Physiological and genetic correlates of fitness in High Arctic breeding shorebirds

Piersma, Theunis; Reneerkens, Jeroen

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Front cover: The setup for the digital cameras on Nansenblokken was improved in 2003 in order to optimise the year-round monitoring of snow and vegetation. Five cameras cover different parts of the Zackenbergdalen and different wavelengths of light (Photos Jørgen Hinkler).

Back of cover: Aage V. Jensens Fonde has kindly provided funds for the aluminium vessel "Aage V. Jensen" to operate in Young Sund and Tyrolerfjord. In this first year of operation the vessel was mainly used for the marine investigations under the new MarineBasis monitoring programme (Photo Søren Rysgaard).

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This book is free of charge and may be ordered from
Danish Polar Center
Strandgade 100H
DK-1401 Copenhagen K
Tel. (+45) 32880100
Fax (+45) 32880101
Email: dpc@dpc.dk

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Executive summary

Hans Meltofte, Charlotte Sigsgaard and Morten Rasch

In 2003, scientists representing 14 different projects used Zackenberg Research Station in June - August, and the total number of person days spent at Zackenberg and Daneborg counted 1,597. The Danish Parliamentary Committee for Science visited the station and was introduced to the research and monitoring activities both at Zackenberg and Daneborg.

Due to a grant from the Danish Environmental Protection Agency it was possible to extend and reorganise the monitoring programme Zackenberg Basic. A new marine monitoring programme, MarineBasis, was introduced, and GeoBasis was extended and reorganised. MarineBasis is maintained by Danish National Environmental Research Institute while the GeoBasis programme is now maintained by the Danish National Environmental Research Institute in cooperation with Institute of Geography, University of Copenhagen.

Due to increased activities on the sea, the Zackenberg fleet was increased with two smaller boats, a rubber boat bought by Danish Polar Center and an aluminium vessel, "Aage V. Jensen", kindly granted by Aage V. Jensens Fonde.

Zackenberg Research Station continued to be an active participant in the network initiatives, SCANNET, ENVINET and CEON. The funding of ENVINET from the European Union ceased in 2003 and unfortunately new funding for the network was not found. The network is continued without external funding.

The summer of 2003 was warm and dry. Mean air temperatures for June, July and August were 2.2°C, 7.7°C and 6.6°C, respectively. June was among the warmest and July and August were the warmest since initiation of climate monitoring in Zackenberg. Similarly, summer temperatures were record-high at Danmarkshavn Weather Station, 300 km north of Zackenberg, where they have a time series of more than 50 years.

Accumulated precipitation during the summer measured 16 mm at the climate station, falling mainly during three rain events. Only during the summer months of 1996 less precipitation was measured.

Spring snow cover was unusual in that it was extensive but relatively thin. As a result, the snow cover was above average on 10 June, but melted faster than experienced before. Due to the extensive snow cover, ice melt on the ponds around the research station was relatively late. Only in the very snow rich year of 1999, did the ponds thaw later. However, since June was very warm, ice melt progressed fast during June, and the larger lakes and Young Sund became ice-free very early. Also the start of running rivers and rivulets was among the earliest recorded so far.

Unprecedented little polar drift ice was found off the coast of Northeast Greenland in autumn 2002, and Young Sund did not have permanent ice cover until late December. On 8 July 2003, the ice in Young Sund had broken up, as early as the exceptionally early season of 2002. The amount of pack ice off Northeast Greenland in autumn 2003 was about as limited as in the unprecedented ice-free season of 2002.

Along the coastline of Young Sund extensive cliff recession was measured at seven out of eight monitoring sites. Increased erosion seems to be a consequence of the longer periods of open sea, as open sea allows for swells to affect the shores without being dampened by sea ice. In this way, large amounts of sediment from land are washed into the fjord, Young Sund. Furthermore, more than 18,000 tons of suspended sediment entered Young Sund from Zackenbergelven's drainage basin.

When we arrived at the station on 3 June, a small stream of melt water was already running in the snow-covered riverbed of Zackenbergelven, and when we left the station on 2 September water was still flowing. About 185 mio. m^3 of water drained from the catchment area during this period, which corresponds to a total water loss of 360 mm/m^2 from the area. Compared to the extraordinary high run off in 2002, where 306 mio. m^3 drained from the area, the run off in 2003 seems low considering the higher temperatures. Less snow in the area probably explains this variation.

In late August, the active layer reached an average depth of 72 cm in ZEROCALM-1 and 63 cm in ZEROCALM-2. For both sites this is the deepest record since 1996, when the plots were established. Relatively early snowmelt and the warm summer temperatures also resulted in the longest period of daily net C accumulation observed in the *Cassiope* heath. The accumulation period lasted from 28 June to 21 August, which is 5-10 days longer than in previous years. Maximum daily net uptake of CO_2 was reached on 17 July, where an amount of 1.4 g C/m^2 accumulated. This is far above the maximum range of 0.9-1.0 g C/m^2 measured in 2000-2002 and must be explained by a foehn on 17 July, where the strong warm wind resulted in very high temperatures late in the evening. At 23:00 a temperature of 17°C was measured, the highest temperature of the season. Fluxes of CO_2 resulted in a total net accumulation of 23 g C/m^2 for the whole measuring season. This is the largest accumulation recorded in four years of monitoring.

Biologically, the result of the late snowmelt in normally early snow free plots was a flowering among the latest recorded – and the fast snowmelt in combination with high temperatures in June resulted in very early flowering in the normally late snow free plots. Late snowmelt in generally early *Saxifraga* plots also impacted opening of the seed capsules, so that in spite of the exceptionally warm summer, seeds were exposed later than or close to average. In contrast, exposure of seeds in most *Papaver* and *Salix* plots was earlier than recorded before, *i.e.* as much as 17-29 days earlier than in recent years. 2003 was again a year of many flowers, but within the range from previous years. This may be due to the fine summer in 2002, as these plants develop their buds the year before. Berry production was poor in the arctic blueberry plot, where only 0.15% of a huge number of flowers resulted in a berry. Crowberries, though, appeared in even larger numbers than recorded earlier.

As a consequence of the warm weather in June and July, several arthropod groups were recorded in considerably higher numbers than most previous years, and some groups were recorded at the highest number so far, *i.e.* Aphidoidea, Lepidoptera, Sciaridae, Tachinidae, Bombus, Ichneumonidae and Scelionidae. Butterflies and moths were particularly abundant this year and were recorded in the highest numbers so far. Almost twice as many Hymenoptera was collected as previous years. Particularly the parsitoids Ichneumonidae, Bracoinidae, Chalcidoidea and Scelionidae were quite numerous. Depredation by *Sympistis zetterstedtii* was recorded in most *Dryas* plots. Woolly-bear *Gynaephora groenlandica* caterpillars were recorded in the highest numbers so far, and so were bumblebees.

2003 was a fine breeding season for most bird species at Zackenberg. Population densities were very much the same as in previous years, but ringed plovers were lower than recorded before, and turnstones remained as low as in 2002. Median 1st egg dates in waders were relatively early, with sanderlings earlier than recorded before, ruddy turnstones among the earliest and dunlins close to average. Numbers of juvenile waders recorded on the intertidal delta flats at the coast of Zackenbergdalen were low, but within the range from previous years. In spite of the record low lemming numbers, at least seven pairs of long-tailed skuas out of an estimated population of 25-29 pairs produced clutches, but only of one egg each. Only one nest was depredated and two young made it through to fledging. Six pairs of red-throated divers nested in Zackenbergdalen, and three of them probably fledged one young each. Only nine pairs of barnacle geese brought goslings to the coast of the valley this year, but numbers of moulting immatures – 369 – in the entire study area was within the range from previous years. A record of 2,092 pink-footed geese was counted during the moult migration in the second half of June and early July. Lesser black-backed gull was found breeding for the first time in East Greenland – a pair with four eggs on Sandøen.

Following the intermediate lemming winter population density of 2000-2002, the population crashed to the lowest level since the start of the BioBasis programme in 1995. At Karupelv, 220 km south of Zackenberg, the lemming population reached a minimum as well, and it is noteworthy that the patterns have been quite parallel at the two sites for nine yeas now. Also numbers of lemming winter nests depredated by stoat dropped to a minimum at both Zackenberg and Karupelv. Also the numbers of predator scats and casts were among the lowest recorded so far.

The daily numbers of musk oxen visible from the research station were above average, only exceeded by 2001 and 2002, and in August, the number of 'musk ox days' inside the census area was the second highest recorded so far. According to records from the line transects, the proportion of calves was 16.5% in 2003 (range 1997-2003: 9-17%) and close to one calf per two cows. The number of cows without a calf (*i.e.* the minimum number of cows with a reproductive potential) was 70% in 2002, and only 42% of these seem to have given birth to a calf still alive in August 2003 (average of 1997-2002 = 60.4%, range: 29.6-120.5%). The snow cover by 10 June seems to have a pronounced effect on the calf-cow ratio, in that a particularly high ratio of cows (with no calves the previous year) have a calf in summers with little spring snow cover.

2003 showed a peak number of 17 arctic fox pups within the 50 km^2 study area, which is remarkable considering the record low number of lemming winter nests and the low number of musk ox carcasses. An estimated 5-6 adults were found inside the same area. Arctic wolfs visited the study area a few times during the summer.

A maximum of 33 walruses was recorded on Sandøen, and a maximum of 126 seals was counted on the fjord ice during June and early July. This is more than twice the number recorded at the past high record from 1999.

The unusually warm summer of 2003 was clearly reflected in the environmental conditions of Sommerfuglesø and Langemandssø. Both lakes were ice-free from the beginning of July, or only second to 2000. Despite this, the average values recorded for conductivity, total nitrogen and total phosphorus were within the range from previous years. The average phytoplankton biomass in terms of chlorophyll *a* reached the highest level recorded in seven years of monitoring, and was even higher than the high level recorded in 2002, which was also characterised by an early ice-melt.

14 research projects were carried out in 2003 based on data from the Zackenberg area. Of these, 3 projects were carried out at Daneborg, while the remaining were carried out either at Zackenberg or based on data from Zackenberg.

1 Introduction

Morten Rasch

After three years with limited research activity at Zackenberg Research Station we achieved a reasonable level of activity in 2003. 39 scientists representing 14 different projects used the station and its facilities from June to August, and when the field season ended at 2 September the number of person days spent at Zackenberg and Daneborg counted 1,597.

It was a special pleasure for us that the Danish Parliamentary Committee for Science and Technology visited the station. During two very busy days the members of the committee were introduced to research and monitoring activities both at Zackenberg and at Daneborg.

Changes in the structure of the monitoring programme Zackenberg Basic

Due to a grant from the Danish Environmental Protection Agency it was possible to extend and reorganise the monitoring programme Zackenberg Basic in accordance with the concept described in the 8th Annual Report (Rasch and Caning 2003). A new marine monitoring programme, MarineBasis, was introduced. This programme is maintained by the Danish National Environmental Research Institute. Further, it has been possible to extend and reorganise the GeoBasis programme.

The GeoBasis programme is now being maintained by the Danish National Environmental Research Institute in cooperation with Institute of Geography, University of Copenhagen. Due to these changes, the Annual Report has also been reorganised. Logistics has changed place from Chapter 2 to Chapter 9. The report of the GeoBasis and ClimateBasis programmes has moved from Chapter 3 to Chapter 2, the BioBasis programme has moved from Chapter 4 to Chapter 3, and Chapter 4 now contains the report of the MarineBasis programme.

New equipment

Due to an increase in activities in Daneborg and Young Sund/Tyrolerfjord over the last years, it was decided to buy an extra rubber boat with more power and space than the existing rubber boats. After arrival by ship in early August, the rubber boat was used intensively for transport of personnel and cargo between Daneborg and Zackenberg.

Also in 2003, Aage V. Jensens Fonde kindly funded a small, specially designed motorboat, Aage V. Jensen, for the activities in Young Sund/Tyrolerfjord. The boat is 7 m long, has an aluminium hull, a back deck with good workspace, a crane and a winch, and a small cabin with two berths. In 2003 the boat was mainly used for activities in relation to the MarineBasis programme, but it was also used for the transport of scientists to field sites within and outside Young Sund/Tyrolerfjord.

International Cooperation

Zackenberg Research Station has over the last three years participated in the two EU-funded networks, ENVINET (European Network of Arctic-Alpine Environmental Research) and SCANNET (Scandinavian/North European Network of terrestrial Field Bases). In 2003 the funding for ENVINET ran out. Attempts were made to achieve funding from the EU sixth framework programme for a continuation and extension of the network but unfortunately we did not succeed with our application. It has however been decided to continue some of the networking activities and the ENVINET homepage without funding. SCANNET was extended with five sites in 2003. Among these are Arctic Station in West Greenland and Sermilik Station in Southeast Greenland. SCANNET will also need to find means for the continuation of the network since the funding is running out in early 2004.

Zackenberg Research Station is also involved in establishing a circum-arctic network of research stations called CEON (Circum-Arctic Environmental Observatories Network). In late 2003 a workshop was held in Stockholm to discuss the purpose and the structure for the network. An implementation plan for the establishment of the network is planned to be presented at Arctic Science Summit Week in Reykjavik in early 2004.

Extension and restoration of the facilities

The building of an accommodation house and a power station at Zackenberg and the planned restoration of the marine facility in Daneborg is still awaiting a clarification of the future ownership of the station. The plan for extending Zackenberg Research Station is part of a comprehensive future plan for the development of the National Park of North and Northeast Greenland. At the moment the Greenland Home Rule is preparing a strategic plan for the different future activities in the National Park and since the activities at Zackenberg Research Station is an integrated part of these plans, we can not achieve funding for the extension of the facility before the strategic plans have been prepared and the future ownership of Zackenberg Research Station has been decided.

At Zackenberg, the restoration of the house that we bought from the Sirius Dogledge Patrol in 2002 was finished. The house contains two bedrooms for station staff.

Plans for the 2004 field season

The 2004 field season at Zackenberg is expected to be as busy as the 2003 field season since several projects already have announced their interest in using the station this year and since the extended Zackenberg Basic is expected to achieve funding also for 2004.

On the logistical site we are considering the possibilities for establishing a VHF-radio repeater system on Dombjerg to achieve better VHF-radio coverage in Store Sødal and in Young Sund / Tyrolerfjord. Due to the increased activity on sea it is an important safety precaution to secure stable radio communication between Zackenberg Research Station and boats on sea.

Further we are planning to improve the speed of our internet connection by installing a satellite based direct connection to the internet. At the moment the internet connection is based on a telephone modem connected to our Inmarsat telephone, and we can only send and receive e-mails at a baud rate of 9800 bits per second.

Further information about Zackenberg Research Station and the study area

Details about Zackenberg Research Station and the study area at Zackenberg has been given in previous annual reports (Meltofte and Thing 1996, 1997; Meltofte and Rasch 1998; Rasch 1999; Caning and Rasch 2000, 2001, 2003; Rasch and Caning 2003) and the information is also available on the Zackenberg website (www.zackenberg.dk). The ZERO Site Manual has all necessary information for scientists planning to use Zackenberg Research Station and it can be obtained together with an application form directly from the Zackenberg website. The secretariat can be contacted on the address: The Zackenberg Research Station Secretariat, Danish Polar Center, Strandgade 100H, DK-1401 Copenhagen K, Denmark, phone (+45) 32880100, fax (+45) 32880101, e-mail mr@dpc.dk.

2 Zackenberg Basic: The Climate Basis and GeoBasis programmes

Charlotte Sigsgaard, Dorthe Petersen, Louise Grøndahl, Hans Meltofte, Jørgen Hinkler, Birger Ulf Hansen, Mikkel Tamstorf and Thomas Friborg

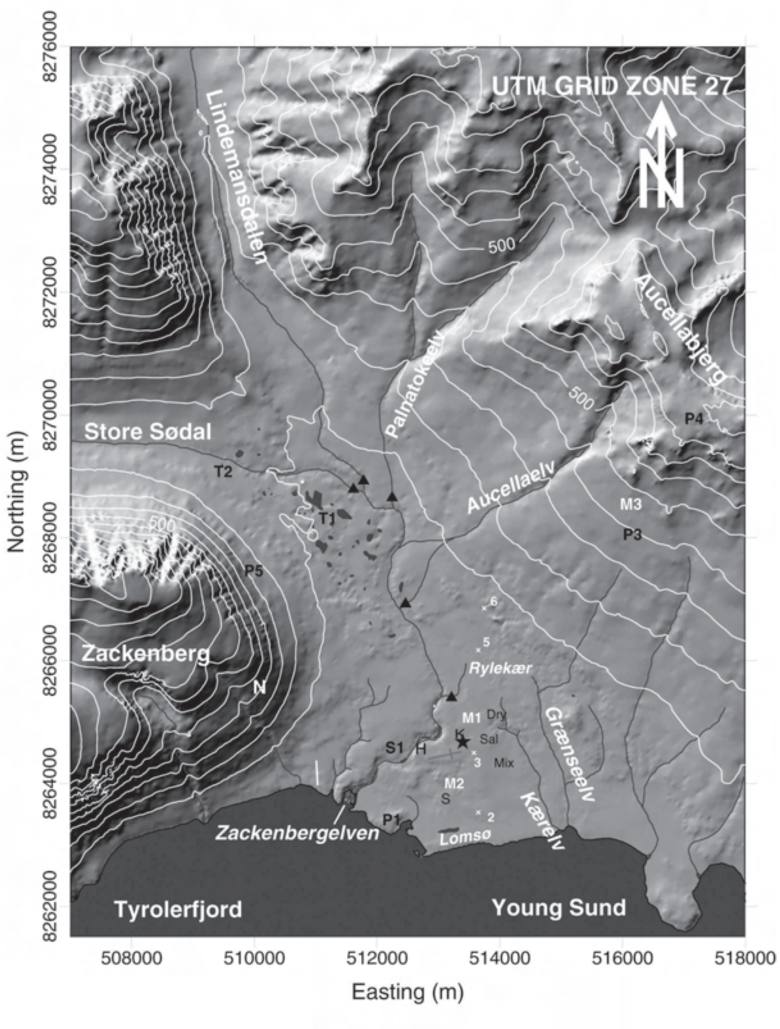


Figure 2.1. Location of GeoBasis and ClimateBasis stations and plots. The climate station is marked with an asterisk. H = Hydrometric station. M1 = Micrometeorological station. M2 and M3 = New snow monitoring and micrometeorological stations. Triangles = Water sampling sites from tributaries to Zackenbergelven. N = Nansenblokken. K, S, Dry, Sal, and Mix = Soil water sites. P1, P3, P4, P5, S1, T1 and T2 = TinyTag temperature sites. Small crosses (x) = Snow stakes 2,3,5 and 6.

The ClimateBasis and GeoBasis programmes collect data describing the dynamics of the physical and geomorphological environment at Zackenberg. This includes the climate in the Zackenberg area, the water balance of Zackenbergelven drainage basin, the sediment, solute and organic matter yield of the Zackenbergelven, the dynamics of selected physical landscape elements, and the seasonal development of the active layer, its temperature conditions and its soil water chemistry. ClimateBasis is operated by ASIAQ, Greenland Survey, who runs and maintains the climate station and the hydrometric station. From 2003 GeoBasis is operated by the National Environmental Research Institute, Department for Arctic Environment in co-operation with Institute of Geography, University of Copenhagen.

The following section is not, as in previous reports, strictly reporting the monitoring from each programme but reporting the combined physical results of the terrestrial monitoring programmes in the six main themes: 1) Meteorological data, 2) Snow, ice and permafrost, 3) River water discharge and chemistry, 4) Precipitation and soil water chemistry, 5) Carbon dioxide flux, and 6) Geomorphology.

During 2003, the GeoBasis monitoring programme was extended and several new installations took place. Two stations for snow and micrometeorological monitoring (M2 and M3) were installed in August. M2 is located in the permafrost monitoring site ZEROCALM-2 and M3 is located *c.* 400 m a.s.l. on the slopes of Aucellabjerg. Also the soil water monitoring programme was expanded and three new plots were installed adjacent to existing BioBasis plant phenology plots. In this way, soil solution chemistry in the dominating soils types covered by different characteristic plant communities in the valley will be examined. Mounting of the digital cameras on Nansenblokken was improved by building a permanent platform, where all cameras were secured in a fixed position. As part of the new setup, larger solar panels and external batteries were installed to improve power supply during winter.

Location of GeoBasis and ClimateBasis stations and plots, referred to in the next sections, are given in Figure 2.1.

At the moment work is done towards establishing a database with direct access to all validated Zackenberg Basic data through the internet homepage: www.zackenberg.dk. Details on GeoBasis methods and sampling procedures will also become

	1996	1997	1998	1999	2000	2001	2002
Yearly mean values							
Air temperature, 2 m above terrain (°C)	-9.2	-10.1	-10.0	-9.5	-10.0	-9.7	-8.6
Air temperature, 7.5 m above terrain (°C)	-8.5	-9.3	-9.4	-8.9	-9.4	-9.2	-
Relative air humidity 2 m above terrain (%)	66	69	73	70	70	71	72
Air Pressure (hPa)	1008.8	1007	1010	1006.3	1007.6	1008.8	1008.7
Incoming shortwave radiation (W/m2)	85	162	171	100	107	112	105
Outgoing shortwave radiation (W/m2)	36	74	70	56	52	56	54
Net Radiation (W/m2)	9	9	12	4	14	13	18
Wind Velocity, 2 m above terrain (m/s)	2.6	3	2.6	3.0	2.4	2.7	2.6
Wind Velocity, 7.5 m above terrain (m/s)	3	3.4	3.2	3.7	3.1	3.2	3
Precipitation (mm w.eq.), total	223	148	181	161	176	236	174
Yearly maximum values							
Air temperature, 2 m above terrain (°C)	16.6	21.3	13.8	15.2	19.1	12.6	14.9
Air temperature, 7.5 m above terrain (°C)	15.9	21.1	13.6	14.6	18.8	12.4	-
Relative air humidity 2 m above terrain (%)	99	99	99	99	100	100	100
Air Pressure (hPa)	1041.5	1035.4	1035.6	1035.3	1035.9	1042.5	1037.9
Incoming shortwave radiation (W/m2)	803	832	833	889	810	818	920
Outgoing shortwave radiation (W/m2)	593	566	632	603	581	620	741
Net Radiation (W/m2)	577	634	557	471	627	602	540
Wind Velocity, 2 m above terrain (m/s)	17.6	22.5	25.6	19.3	20.7	20.6	21.6
Wind Velocity, 7.5 m above terrain (m/s)	22.2	26.2	29.5	22.0	23.5	25.0	25.4
Yearly minimum values							
Air temperature, 2 m above terrain (°C)	-33.7	-36.2	-38.9	-36.3	-36.7	-35.1	-37.7
Air temperature, 7.5 m above terrain (°C)	-31.9	-34.6	-37.1	-34.4	-34.1	-33.0	-
Relative air humidity 2 m above terrain (%)	20	18	31	30	19	22	23
Air Pressure (hPa)	956.2	953	974.7	960.6	968.5	972.2	954.5
Incoming shortwave radiation (W/m2)	0	0	0	0	0	0	0
Outgoing shortwave radiation (W/m2)	0	0	0	0	0	0	0
Net Radiation (W/m2)	-86	-165	-118	-100	-129	-124	-148
Wind Velocity, 2 m above terrain (m/s)	0	0	0	0	0	0	0
Wind Velocity, 7.5 m above terrain (m/s)	0	0	0	0	0	0	0

Table 2.1. Yearly mean, maximum and minimum values of climate parameters 1996 to 2002.

available from this homepage. Until the database is ready, data collected by ClimateBasis and GeoBasis are available and can be ordered free of charge from ASIAQ (dop@asiaq.gl) and Institute of Geography (cs@geogr.ku.dk), respectively.

2.1 Meteorological data

The meteorological station at Zackenberg was constructed in the summer of 1995. Technical specifications of the station are described in Meltofte and Thing (1996). In the 1997 field season, the radiation sensors from the eastern mast were moved to a separate mast (Meltofte and Rasch, 1998). Once a year the sensors are calibrated and checked by ASIAQ, Greenland Survey.

Meteorological data from 2002

In 2002, the mean air temperature measured 2 m above terrain was –8.6°C, the maximum temperature was 14.9°C in late June and the minimum temperature was –37.7°C in early March (Table 2.1). The period with frequent temperatures above 0°C started in mid May and ended in mid September (Figure 2.2). The yearly mean air temperature was the highest among the years 1996 to 2002 (Table 2.2). This was mainly due to a warm autumn with the monthly mean temperatures in September and October being the highest measured. In the winter period, on the other hand, the monthly mean temperatures in February and March was among the lowest measured.

The total amount of measured precipitation in 2002 was 174 mm, *i.e.* a medium year. The precipitation during the summer period occurred primarily in August

		Shortwave Rad.		Net Rad.	PAR	Air temperature			Precipitation	Wind velocity		Vind
		W/m²	W/m²	W/m²	µmol/m²/s	°C	°C	°C	mm	m/s	m/s	direction
		mean	mean	mean	mean	mean	min	max	total	mean	max 1)	dominant
		in	out			2 m	2 m	2 m		7.5 m	7.5 m	7.5 m
	Jun	291	106	107	-	1.9	-3.7	13.6	4	1.8	9.9	SE
1996	Jul	208	20	137	-	5.8	-1.5	16.6	7	2.7	12.1	SE
	Aug	142	19	69	-	4.4	-4	14.1	2	2.9	12.5	S
	Jun	216	107	88	-	2.2	-4.4	12.0	23	2.4	14.1	ESE
1997	Jul	225	23	130	-	3.7	-1.0	15.3	28	2.7	13.8	SE
	Aug	174	21	74	-	5.0	-3.0	21.3	16	2.8	13.3	SE
	Jun	269	172	51	-	0.9	-3.0	9.6	5	1.6	8.1	SE
1998	Jul	204	20	126	-	4.7	-2.6	13.8	33	2.2	12.1	SE
	Aug	123	12	64	-	4.6	-1.8	11.5	55	2.4	12.2	ESE
	Jun	294	206	33	-	1.5	-4.5	10.4	2	2.3	15.0	-
1999	Jul	212	32	123	-	6.2	-0.7	15.1	21	2.6	14.8	-
	Aug	143	16	73	-	2.9	-2.7	15.2	11	2.5	14.9	SE
	Jun	294	103	126	-	1.9	-6.2	11.7	10	2.1	15.1	SE
2000	Jul	228	27	141	-	5.3	-1.2	19.1	13	2.9	15.9	SE
	Aug	153	19	82	-	4.0	-3.5	11.6	0	2.3	13.4	SE
	Jun	293	168	67	-	2.1	-4.9	11.9	25	2.1	13.3	-
2001	Jul	231	27	146	-	4.9	-1.5	11.8	7	2.9	13.1	-
	Aug	180	20	84	-	5.8	-0.8	12.6	21	2.8	14.4	-
	Jun	344	151	113	-	2.6	-2.8	14.9	1	1.6	6.8	SE
2002	Jul	205	23	105	424	5.7	-0.9	13.8	3	2.6	9.9	SE
	Aug	128	15	51	272	5.0	-3.1	11.6	21	2.8	12.9	SE
	Jun	294	108	106	612	2.2	-4.8	14.7	7	1.6	5.4	SE
2003	Jul	211	26	96	431	7.7	1.8	16.7	6	2.8	14.2	SE
	Aug	151	20	56	299	6.6	-0.5	15.4	3	2.5	10.1	SE

Table 2.2. Climate parameters for June, July and August, 1996 to 2003. 1) Wind velocity, max is the maximum of 10 minutes mean values.

whereas June and July were very dry (Table 2.2).

The mean air pressure was 1008.7 hPa. The air pressure was generally more stable during summer than during winter. Mean relative humidity was 72%, and the relative humidity was highest during the summer period

Unfortunately the net radiation sensor was out of order from February until May. Monthly mean net radiation was positive in June, July, August and September and negative in the remaining months for which data exist. The same distribution has been seen in previous years. The mean net radiation was 18 W/m^2, which is higher than previous years.

Mean wind speed 2 m and 7.5 m above the ground was 2.6 m/s and 3.0 m/s, respectively. The highest 10 minutes mean value was 21.6 m/s at 2 m above ground and 25.4 m/s at 7.5 m above ground. The wind speeds were generally higher in winter than in summer.

The wind direction sensor was replaced in the summer 2001, and at the inspection in the summer 2003 it was noticed that the wind direction was measured relative to magnetic north. The wind directions given in Table 2.2, 2.3, 2.4 and Figure 2.2 have been corrected to be relative to geographic north. Note that the wind direction due to this differs from the results published in Rasch and Caning (2003). The yearly wind statistic for 2002 is in good agreement with the years 1997, 1998 and 2000. Wind statistics for the remaining years are not given due to significant periods with missing data. In 2002, the winds were coming from N and NNW 38% of the time, mainly during the winter period, and from ESE to SSE *c.* 22% of the time, mainly during the summer period (Table 2.3 and 2.4).

In the 2002 field season measurements of photosynthetic active radiation (PAR) were started. The PAR-sensor measures incoming radiation in the wave band 400-700 nm that is a specific part of the incoming solar radiation. As expected a high correlation between the measured PAR and incoming short wave radiation was found (R^2=0.98).

Meteorological data from 2003

Monthly mean values of the climatic parameters show the same trend as the pre-

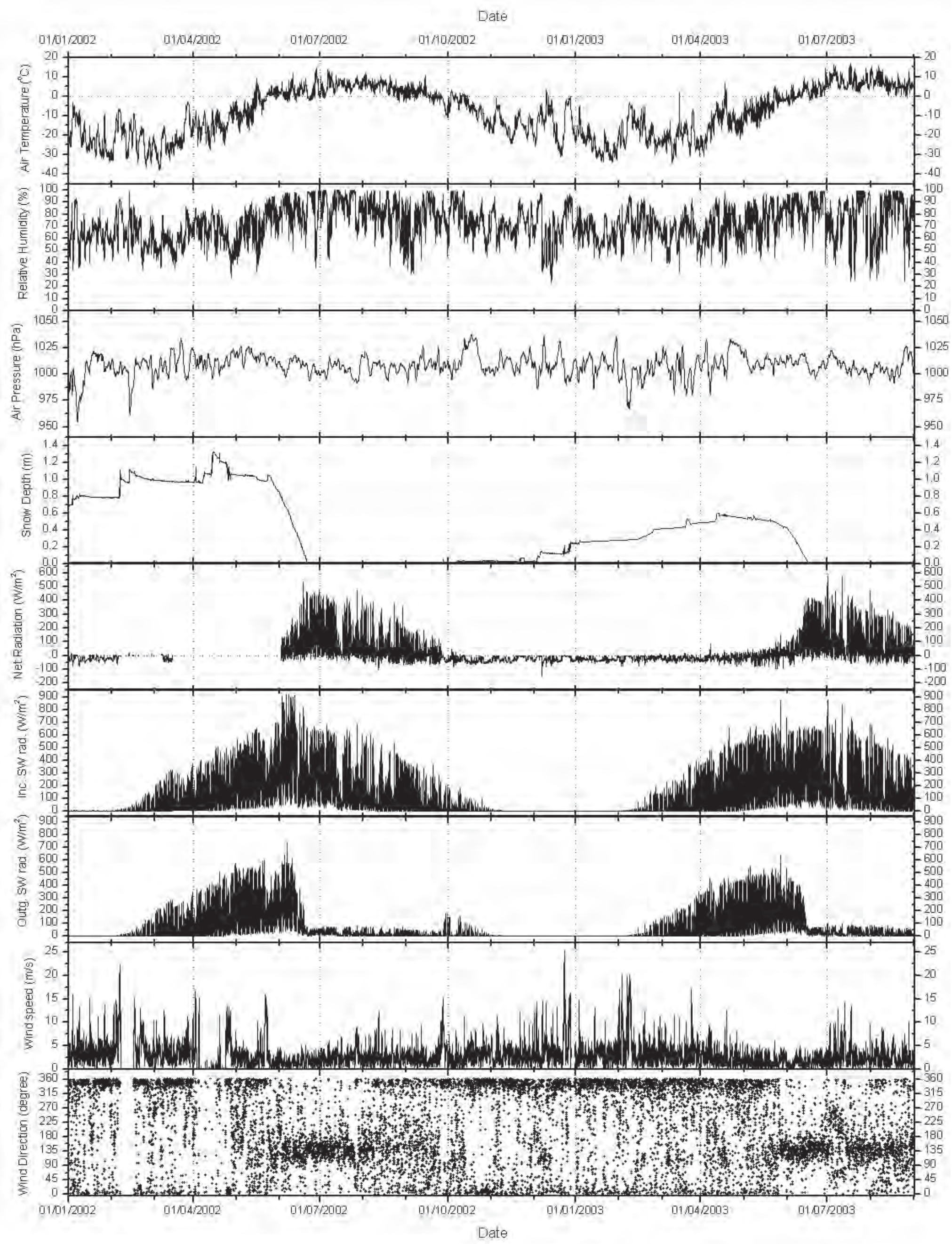


Figure 2.2. Variation of selected climate parameters 2002 and part of 2003. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation, outgoing short wave radiation, wind speed and wind direction. Wind speed and direction are measured 7.5 m above terrain. The remaining parameters are measured 2 m above terrain.

Figure 2.3. Micrometeorological station (M2) in the middle of ZEROCALM 2.

vious years (Table 2.2). In 2003 the monthly mean temperatures became positive in June (Figure 2.2). The monthly mean temperatures in July and August were the highest measured during the years 1996-2003. The minimum temperatures in these months were the highest measured, whereas the maximum temperatures were not extreme (Table 2.2). These high summer temperatures are in accordance with unprecedented warm summer temperatures at Danmarkshavn, 300 km north of Zackenberg.

The last snow disappeared from the measuring station 17 June giving a large positive net radiation in the following period.

Dominant wind direction was N and

	Air Temperature °C 2.0 m	Air Temperature °C 7.5 m	Rel. humidity %	Air Press. hPa	Net Rad. W/m2	Shortwave Rad. W/m2 In	Shortwave Rad. W/m2 Out	Wind Velocity m/s 2.0 m	Wind Velocity m/s 7.5 m	Dominant Wind Dir. 7.5 m
2002										
Jan	-21.7	-20.3	64	1001.7	-22	0	0	3.0	3.6	N
Feb	-21.0	-20.1	65	1003.5	-	8	8	3.6	4.0	N
Mar	-22.7	-	59	1009.8	-	68	60	2.9	3.7	N
Apr	-14.6	-	65	1011.4	-	154	144	2.4	2.2	N
May	-4.1	-	72	1016.6	-	260	219	2.1	2.6	N
Jun	2.6	2.5	84	1007.2	113	344	151	1.4	1.6	SE
Jul	5.7	5.3	87	1004.5	105	205	23	2.3	2.6	SE
Aug	5.0	4.9	81	1007.5	51	128	15	2.4	2.8	SE
Sept	0.5	0.8	76	1009.0	5	73	14	2.5	3.0	N
Oct	-5.8	-5.0	77	1015.2	-31	14	11	2.5	3.0	N
Nov	-14.5	-13.6	72	1010.7	-23	0	0	2.7	3.0	NNW
Dec	-13.7	-12.8	69	1007.6	-25	0	0	3.7	4.4	NNW
2003										
Jan	-24.4	-23.0	65	1009.6	-26	0	0	2.3	3.1	NNW
Feb	-17.0	-16.1	73	999.0	-20	8	6	3.1	4.6	NNW
Mar	-21.5	-20.6	65	1005.6	-22	61	51	2.8	3.3	NNW
Apr	-13.7	-13.0	69	1015.2	-19	165	140	2.2	2.5	NNW
May	-5.6	-5.3	77	1010.9	-5	266	213	1.5	1.8	N
Jun	2.2	1.8	86	1009.6	106	294	108	1.5	1.6	SE
Jul	7.7	7.3	76	1007.6	96	211	26	2.5	2.8	SE
Aug	6.6	6.5	77	1007.0	56	151	20	2.2	2.5	SE

Table 2.3. Monthly mean values of climate parameters, January 2002 - August 2003.

NNW from January to May, and SE in the summer months from June to August (Figure 2.2 and Table 2.3).

The precipitation during the summer was very sparse; only the summer of 1996 received less water (Table 2.2).

Figure 2.4. Micrometeorological station (M3) 420 m a.s.l. on the Aucellabjerg slope.

2.2 Snow, ice and permafrost

New micrometeorological stations

In order to monitor the spatiotemporal variations in the snow cover and the local microclimate two micrometeorological stations (M2 and M3) were established in the summer of 2003. Parameters recorded at these stations will be used for modelling of the snow cover and the energy-, radiation- and water balance within Zackenbergdalen.

Station M2 (UTM: 8264019 mN, 513058 mE) was placed in the middle of ZERO-CALM 2 between column 6 and 7 and between row 5 and 6, *c.* 17 m a.s.l. (Figure 2.3). It is on a south-facing slope on the vegetation boarder between an upper zone of white arctic bell-heather (*Cassiope tetragona*) and a lower zone of willow snow-patch vegetation. The location was chosen not only because it is in ZERO-CALM-2, but also because it is one of the first places were snow accumulates in early autumn. From earlier years it is known that snow accumulation can reach 2-3 meters on the slope, and the snow can persists until mid or late summer.

Station M3 (UTM: 8268250 mN, 516126 mE) was placed on the southwest facing

Year	1997			1998			2000			2002		
Direction	Freq.	Velocity, m/s		Freq.	Velocity, m/s		Freq.	Velocity, m/s		Freq.	Velocity, m/s	
	%	mean	max	%	mean	max	%	mean	max	%	mean	max
N	10.1	3.9	26.2	7.9	4.2	29.5	10.8	3.8	20.5	19.9	4.7	23.5
NNE	3.9	3.5	19.5	2.5	2.3	14.4	2.9	1.8	14.2	4.3	3.1	25.4
NE	2.9	2.8	19.4	2	2.9	17.9	2.5	2.7	15.3	2.5	2.1	10.9
ENE	3	2.2	12.9	2.4	1.9	12.1	2.8	2.2	10.4	2.7	2.7	15.6
E	5.1	2.2	8.3	4.3	1.9	8.0	4.7	2.2	8.1	3.7	2.1	10.4
ESE	7.3	2.3	10.3	7.9	2.1	6.7	8.0	2.3	9.8	6.7	2.2	9.9
SE	7.2	2.5	18.1	8.2	2.1	7.9	9.5	2.7	7.5	8.4	2.4	8.3
SSE	4.1	2.3	16.2	4.5	2.1	8.3	4.7	2.5	8.4	6.7	2.5	8.4
S	3.3	2.5	9.9	4.2	2.2	7.8	3.3	2.4	6.5	4.2	2.6	8.6
SSW	2.2	2.3	11.5	3.3	2.1	7.0	2.2	2.1	7.8	3.3	2.5	13.4
SW	2	2.2	12.2	3.1	2.1	8.5	2.2	2.1	7.8	2.6	2.1	8.2
WSW	2.5	2.5	15.9	3.3	2.4	7.5	2.4	2.5	10.5	2.6	2.3	8.0
W	2.7	2.6	16.9	3.1	2.1	9.8	2.4	2.5	23.5	2.7	2.4	16.9
WNW	3.7	2.9	15.9	3.8	2.5	14.2	3.6	2.7	19.0	2.6	2.7	16.2
NW	8	3.9	25.1	7.7	3.8	21.1	7.1	3.7	18.3	4.7	3.2	15.2
NNW	27.9	5.1	25.8	26.8	5.1	23.5	26.7	5.0	20.1	18.1	5.0	24.5
Calm	4.1			5			4.3			4.2		

Table 2.4. Wind statistics for 1997, 1998, 2000 and 2002 based on wind velocity and direction measured 7.5 m above terrain. Calm wind is defined as wind speed lower than 0.5 m/s. Max speed is maximum of 10 minutes mean values. The frequency for each direction is given as percent of the time for which data exist. Missing data amount to less than 8% of data for the entire year and less than 20 days in one month.

slope of Aucellabjerg *c.*100 m SE of point 101 on the ZERO-line and *c.* 420 m a.s.l. (Figure 2.4). The station is placed on the dry part of a solifluction area, fairly densely vegetated and dominated with *Dryas-Carex nardina*. Temperature inversions with cold low clouds or fog coming from the outer coast dominate the climate in periods in Zackenbergdalen. The placing of station M3 above the inversion layer will hopefully contribute to a more detailed understanding of the cooling and shading effects on especially the altitudinal distribution of snow cover and vascular plants within the Zackenbergdalen

Campbell CM10 tripods were used to provide the weather stations with a rugged support structure for both instrumentation enclosure, meteorological sensors and solar panel. Each leg of the tripod was secured to the ground by putting a 1.5 cm wide and 0.8 m long thread bar through the poles in each foot, and secure the bars to the feet with bolts. Data from the different sensors are logged by a CR10 Campbell datalogger and stored in a SM16M storage module. Snow depth and soil moisture sensors are scanned and logged every six hours, while the rest of the sensors are scanned every minute and logged every 30 minutes (Table 2.5).

Only data for August 2003 are available, but preliminary graphs (Figure 2.5) show that the temperature lapse rate between M2 and M3 was negative (less than 0.0 °C/100 m) in 34 % of the time, mainly in periods with low cold clouds or fog, while the temperature lapse rate was above 0.5°C/100 m in 35 % of the sunny periods.

Snow depth

In 1997, automatic measurements of snow depth were started in Zackenbergdalen near the meteorological station (see Meltofte and Rasch 1998). At the inspection of the station in August 2003 the sonic range sensor was found to have been working only periodically due to a partly broken cable. The sonic sensor was replaced.

The snow depth during the winter is summarised for all six winters in Table 2.6 and the accumulation for all years is shown in Figure 2.6. In the winter 2002/2003 the snow depth reached 0.1 m on 6 December, which is relatively late compared to a normal mid November. The maximum measured snow depth was 0.6

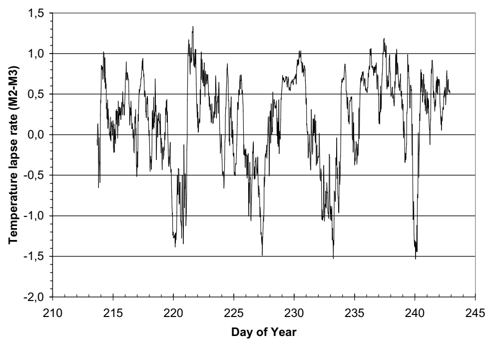


Figure 2.5. The temperature lapse rate between M2 and M3 in August 2003.

Log interval	Parameter	Unit	Sensor type	Elevation
30 min	Gust	m/sec	A100R	2.5 m
30 min	Wind Speed	m/sec	A100R	2.5 m
30 min	Wind Dir	°	W200P	2.5 m
30 min	Rel. Hum.	%	MP103A	2.5 m
30 min	Air Temp	°C	PT100	2.5 m
6 hour	Snow Depth	cm	SR50	2.5 m
30 min	RED 660 nm	μmol/m²/sec	SKR110	2.5 m
30 min	NIR 730 nm	μmol/m²/sec	SKR110	2.5 m
30 min	RVI	none	SKR110	2.5 m
30 min	NDVI	none	SKR110	2.5 m
30 min	Si	W/m²	CNR1	2.5 m
30 min	Su	W/m²	CNR1	2.5 m
30 min	Li	W/m²	CNR1	2.5 m
30 min	Lu	W/m²	CNR1	2.5 m
30 min	SoilTemp (1 cm)	°C	105T Type T	-1 cm
30 min	SoilHeat	W/m²	HFT3	-1 cm
30 min	SoilTemp (10 cm)	°C	105T Type T	-10 cm
30 min	SoilTemp (30 cm)	°C	105T Type T	-30 cm
30 min	SoilTemp (60 cm)	°C	105T Type T	-60 cm
6 hour	SoilMoist. (10 cm)	%	Theta-ML2x	-10 cm
6 hour	SoilMoist. (30 cm)	%	Theta-ML2x	-30 cm

Table 2.5. Sensor type, measuring units, sensor level and logging interval for M2 and M3.

m. That is app. the same level as in the winters 1999/2000 and 2000/2001, but only half the maximum level of the winters 1998/1999 and 2001/2002.

Measuring of precipitation in the form of snow is uncertain, especially if it takes place when it is windy and cold (Vejen *et al.* 2000). As the air temperature rises during spring, the snow settles and hence snow depth decreases and snow density increases. Melt water seep down through the snow and freezes as it reaches the frozen ground. When the temperature at the ground reaches 0°C melt water drains away as overland flow. Temperature at the ground surface will stay at 0°C until the snow has melted. In Table 2.6, the snow depth at the time when the ground temperature reaches 0°C is given as "snow depth at spring". Assuming a density for

Table 2.6. Key figures describing the amount of snow in 6 winters: the maximum snow depth during the winter and the date when it is reached, the date when the snow depth reaches 0.1 m in the beginning of winter, and the date in spring when the depth is less 0.1 m (due to melting). The snow depth, when the melting snow becomes saturated with water, is given as "snow depth at spring" (see text). The equivalent amount of water is calculated assuming a density of 400 kg/m³. Furthermore, precipitation when snow is present on the ground is given.

	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03
Max. snow depth, meter	0.9	1.3	0.5	0.7	1.3	0.6
Max. snow depth reached	29 Apr	11 Mar	19 May	25 Mar	15 Apr	13 Apr
Snow depth exceeds 0.1m from	19 Nov	27 Oct	1 Jan	16 Nov	19 Nov	6 Dec
Snow depth is below 0.1m from	25 Jun	3 Jul	14 Jun	24 Jun	20 Jun	14 Jun
Snowdepth at spring, meter	0.58	0.91	0.38	0.5	0.7	0.28
Snowdepth at spring, mm w.e.	232	364	152	200	280	112
Winter precipitation, mm w.e.	182	176	149	177	130	175

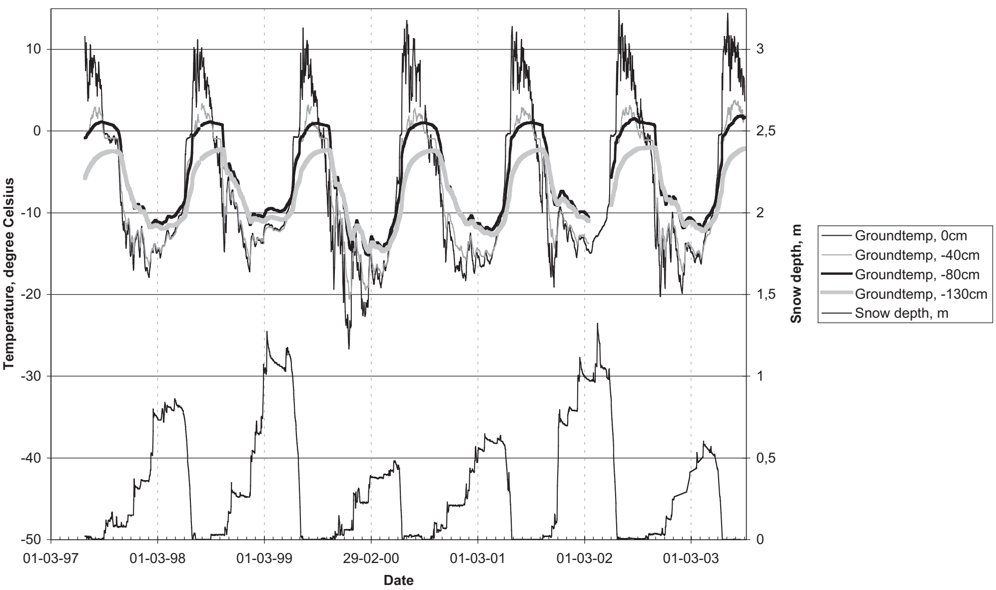


Figure 2.6. Daily mean temperatures at ground surface and in 40 cm, 80 cm and 130 cm below the surface. Snow depth is shown in the lower half of the figure. Only data from years with snow depth measurements are shown.

this compact snow of 400 kg/m^3 approximate values for the winter precipitation can be calculated. These values are in reasonable accordance (0-40% difference) with the precipitation measured at the climate station during winter in four out of six years. For the two years with the largest amount of snow during winter, the values based on "snow depth at spring" are more than twice the measured precipitation. Uncertainties exist in both methods. Snow depth measured at the sonic range snow depth sensor is assumed to be representative for the precipitation, *i.e.* drift of snow is assumed in total not to accumulate or remove snow from the measuring spot. The density of the snow has not been measured.

Station	1998	1999	2000	2001	2002	2003
0	-	>101	44	79	131	-
2	-	-	-	177	265	197
3	-	-	-	-	205	91
4	81	118	48	61	110	50
5	-	-	-	-	-	50
6	-	-	-	-	90	33

Table 2.7. Snow depth at six permanent stations in Zackenbergdalen in late May 1998-2003 given as the highest daily average during 21-31 May. Stations 0 and 4 are the sonic sensors at the hydrometric station in Zackenbergelven and at the climate station. Stations 2, 3, 5 and 6 refer to snow stakes installed in 2001. Unfortunately, the station at Zackenbergelven was not working this year. Station 1 and 7 will be included next year when snow depth data are available from the new micrometeorological stations, M2 and M3 (Figure 2.3 and 2.4).

Snow cover

Spring snow cover was unusual as it was relatively extensive but thinly distributed. Snow depth at five permanent sites was much shallower than in 2002 – less than half at three sites (Table 2.7). The result was that even though snow cover was extensive at the end of winter, it melted away at a rate nearly as fast as in 2000, which is the most snow poor year we have recorded so far (with respect both to depth and extent). On 10 June, which has been chosen as a good early season indicator for biological conditions, snow cover was above average in most sections east of Zackenbergelven, while it was below average only west of the river and in section 6 (Table 2.8; see Figure 4.1 in Caning and Rasch 2003 for map of sections).

Figure 2.7 displays the snow cover extent within the central part of Zackenbergdalen throughout the melting season together with corresponding data from the 1998, 1999, and 2000 seasons. Within the period, where snow coverage has been recorded with digital cameras, the 1999 and 2000 seasons represent years with maximum and minimum snow coverage, respectively. Considering that 2003 (like 2000) had a limited snow accumulation at the end of winter, the snow cover during the very early part of the melting season was unusually extensive (Figure 2.7). Until around 13 June the snow cover was almost as extensive as in 1998 (which had snow accumulation and extent slightly above average). Afterwards, snow depleted at a faster rate than ever recorded in the valley, and from late June and onwards the 2003

	Area (km²)	Area hidden (%)	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean
1 (0-50 m)	3.52	3.5	78	74	65	77	91	60	73	77	68	74
2 (0-50 m)	7.97	1.2	89	88	90	85	91	57	87	87	92	85
3 (50-150 m)	3.52	0.0	88	81	83	83	94	51	89	82	83	82
4 (150-300 m)	2.62	0.0	73	74	68	66	86	33	79	56	73	68
5 (300-600 m)	2.17	0.0	16	54	73	43	85	31	56	36	49	49
6 (50-150 m)	2.15	75.3	86	86	84	87	98	55	84	78	74	81
7 (150-300 m)	3.36	69.3	90	81	76	90	97	54	84	74	90	82
8 (300-600 m)	4.56	27.5	49	55	66	64	84	37	45	52	66	58
9 (0-50 m)	5.01	6.2	92	87	96	91	97	54	96	96	100	90
10 (50-150 m)	3.84	2.9	94	85	95	97	98	60	97	93	100	91
11 (150-300 m)	3.18	0.2	91	72	86	92	96	77*	97	88	100	90
12 (300-600 m)	3.82	0.0	40	66	89	68	89	65	73	65	98	72
13 (Lemmings)	2.05	1.0	89	80	76	80	87	58	83	83	89	81
Total area	**45.70**	**12.9**	**76**	**77**	**81**	**80**	**92**	**54**	**82**	**77**	**83**	**78**

* Partly cloud covered, giving too high snow cover

Table 2.8. Area size and snow cover on 10 June in 13 bird and mammal study sections in Zackenbergdalen and on the slopes of Aucellabjerg 1995-2003 (see Figure 4.1 in Caning and Rasch 2003 for map of sections). Photos were taken from a fixed point 477 m a.s.l. on the east facing slope of Zackenberg mountain within +/- 3 days of 10 June and extrapolated according to the methods described by Pedersen and Hinkler (2000). Furthermore, the proportions of the areas not visible from the photo point are given. Data from 1995 and 1996 are from satellite images taken on 9 and 11 June.

Table 2.9. Visually estimated dates of 50% ice cover on selected ponds and lakes around the research station, together with start of running water in rivers and break up of the fjord ice in Young Sund 1995-2003. "West pond" and "East pond" are the two ponds in Gadekæret north of the runway, "South pond" is the major pond in Sydkærene south of the runway, "Rivulets" are the streams draining the slopes of Aucellabjerg through Rylekærene, Zackenbergelven gives the initial date of genuine flow in the river, and Young Sund is divided between break up of the fjord ice off Zackenbergdalen and in all of the fjord. The 50% ice cover date for Lomsø is tentative, as it is estimated from the research station.

	1995	1996	1997	1998	1999	2000	2001	2002	2003
West pond		4.6	Dry	5.6	10.6	30.5	8.6	2.6	9.6
East pond		3.6	Dry	6.6	16.6	1.6	6.6	3.6	12.6
South pond		<3.6	30.5	7.6	12.6	1.6	8.6	3.6	8.6
Lomsø		4.7	2.7	8.7	10.7	1.7	4.7	30.6	29.6
Rivulets		<6.6	11.6	11.6	15.6	4.6	10.6	4.6	3.6
Zackenbergelven	<26.5	<3.6	4.6	10.6	20.6	8.6	8.6	4.6	30.5
Young Sund (Zac.)		13.7	19.7	14.7	14.7	8.7	13.7	1.7	5.7
Young Sund (all)	12.7	13.7	22.7	22.7	24.7	17.7	23.7	8.7	8.7

snow cover extent was almost identical to what was recorded in 2000. At the very end of the melting period (mid July and onwards) the 2003 extent was even slightly below the 2000 extent, and some snow patches that have been perennial in all previous years melted away by the end of the summer 2003. For example, it was the first time in our study period that the snow patch in Solkæret just west of the station totally disappeared by the end of August (measurements from this snow patch is described in section 3.4.3 Meltofte and Thing 1997)

When looking at the snow distribution in different altitudinal zones (Figure 2.8), 2000 and 2003 also differ as snow cover depletion at higher altitudes took place at a more constant rate in 2003 than in 2000. This reveals an end of winter snow distribution with more distinct snow accumulation at higher altitudes in 2003 than in 2000.

New and improved snow monitoring station on Nansenblokken

In early June, a major improvement was made to the photographic snow monitoring station on Nansenblokken, 477 m a.s.l., on the east facing slope of Zackenberg mountain. The improvement was done in order to make room for a larger number of automatic cameras, and to increase the size of the power supply. The cameras were installed on a platform at fixed orientations (Figure 2.9), which makes geometric image-rectification more accurate and less time consuming. In addition to the three standard digital cameras already placed at the location, two multispectral cameras were included in the setup. These cameras are able to monitor vegetation activity and make classification of more than just two surface types (snow or non-snow) possible. However, due to technical difficulties they only run during summertime, and need to be inspected at regular time intervals.

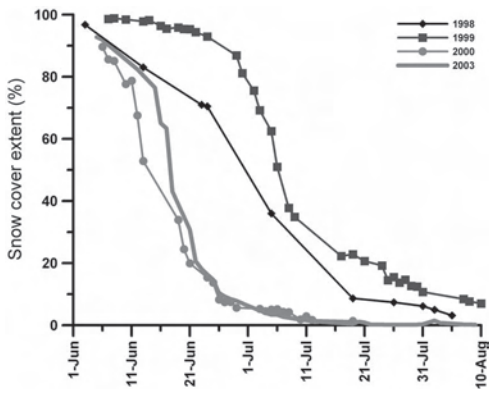


Figure 2.7. Snow cover depletion curves for the central part of Zackenbergdalen 1998, 1999, 2000 and 2003.

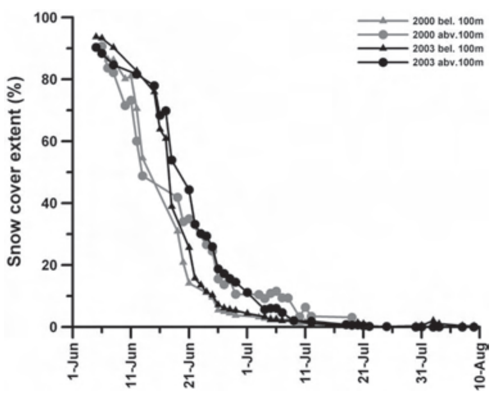


Figure 2.8. Snow cover depletion curves for different altitudinal zones (below and above 100 m) in 2000 and 2003.

Table 2.10. Maximum active layer depth in ZEROCALM-1 and ZEROCALM-2 measured late August, 1997-2003.

	1997 (cm)	1998 (cm)	1999 (cm)	2000 (cm)	2001 (cm)	2002 (cm)	2003 (cm)
ZEROCALM-1	61.7	65.6	60.3	63.4	63.3	70.5	72.5
ZEROCALM-2	57.4	59.5	43.6	59.8	59.7	59.6	63.4

Ice melt on ponds and lakes

Due to the extensive snow cover early in the season, ice melt on the ponds north and south of the research station was relatively late (Table 2.9). Only in the very snow rich year of 1999, the ponds thawed later than in 2003. However, already when we arrived on 3 June, a number of very small and exposed ponds were ice-free, but all ponds north and south of the research station were not ice-free until 17 June. In mid July a few ponds started to dry out, and by late July a number of ponds were dry.

Since snow and ice melt progressed fast during June, Lomsø became free of ice earlier than recorded before (Table 2.9). Already on 5 July, virtually all ice had disappeared. The ice melt on Sommerfuglesø in

Figure 2.9. The new photo equipment on Nansenblokken, Zackenberg mountain, monitoring the snow cover.

	1996	1997	1998	1999	2000	2001	2002
Yearly mean temperature							
0 cm below surface (°C)	-8.4	-8.2	-7.3	-8.2	-8.7	-7.6	-6.4
2.5 cm below surface (°C)	-8.3	-8.2	-7.7	-8.0	-8.4	-7.7	-5.2
5 cm below surface (°C)	-7.7	-7.6	-6.7	-7.3	-8.2	-7.1	-6.0
10 cm below surface (°C)	-7	-7	-6.2	-6.6	-7.0	-6.3	-3.9
20 cm below surface (°C)	-8.2	-8.4	-7.4	-8.0	-8.8	-7.7	-6.6
40 cm below surface (°C)	-8.6	-9	-8.2	-8.4	-9.0	-8.3	-6.1
60 cm below surface (°C)	-6.5	-7.1	-6.3	-6.6	-7.5	-6.5	-5.4
80 cm below surface (°C)	-6.1	-6.8	-6.1	-6.3	-6.9	-6.2	-3.9
100 cm below surface (°C)	-7.4	-8.2	-7.3	-7.6	-8.6	-7.6	-6.6
130 cm below surface (°C)	-7.6	-8.6	-7.7	-7.8	-8.6	-7.9	-5.8
Maximum yearly temperature							
0 cm below surface (°C)	18.7	16.6	16.5	18.4	23.1	21.0	22.6
2.5 cm below surface (°C)	19.6	24	19.9	21.2	13.9	13.0	14.9
5 cm below surface (°C)	16.3	16.4	17	18.4	12.5	11.6	13.3
10 cm below surface (°C)	12.9	13.6	13	15.2	11.7	11.4	12.4
20 cm below surface (°C)	-	7.5	8	8.8	7.6	7.6	8.2
40 cm below surface (°C)	3.7	3.1	3.5	6.2	2.9	3.1	3.2
60 cm below surface (°C)	2.6	2.7	2.8	8.2	2.4	2.6	3.4
80 cm below surface (°C)	1.2	1.2	1.2	1.0	1.1	1.1	1.6
100 cm below surface (°C)	-0.7	-0.7	-0.6	0.0	-0.7	-0.6	-0.5
130 cm below surface (°C)	-2.6	-2.4	-2.2	-2.3	-2.3	-2.2	-2.0
Minimum yearly temperature							
0 cm below surface (°C)	-23.7	-26.2	-18.1	-26.9	-23.0	-19.5	-20.6
2.5 cm below surface (°C)	-22.6	-25.5	-18.1	-25.2	-21.9	-18.0	-20.1
5 cm below surface (°C)	-21.9	-24.8	-17.3	-24.1	-20.9	-17.0	-19.0
10 cm below surface (°C)	-20.9	-23.8	-16.4	-23.1	-20.2	-16.3	-18.0
20 cm below surface (°C)	-	-24.2	-17.3	-22.9	-20.6	-16.9	-18.0
40 cm below surface (°C)	-20	-22.3	-16.6	-20.7	-19.5	-16.0	-15.6
60 cm below surface (°C)	-15.4	-17.3	-13.2	-16.1	-16.2	-13.0	-11.9
80 cm below surface (°C)	-12.9	-15.4	-11.9	-14.6	-15.2	-12.2	-10.6
100 cm below surface (°C)	-14.2	-16.1	-12.9	-15.3	-16.1	-13.3	-12.1
130 cm below surface (°C)	-12.6	-14.5	-12	-13,2	-14.8	-12.8	-11.1

Table 2.11. Yearly mean, maximum and minimum soil temperatures in different depths 1996-2002.

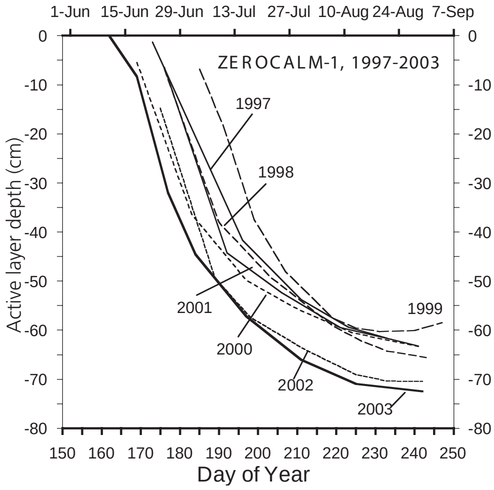


Figure 2.10. Active layer development in ZEROCALM-1, 1997-2003.

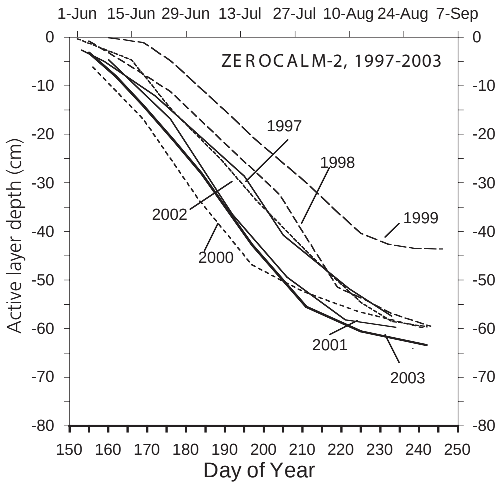


Figure 2.11. Active layer development in ZEROCALM-2, 1997-2003.

Morænebakkerne was at least as early as in the very early season of 2000, while Langemandssø was a bit later (see Table 3.42). Already on 2 July, Store Sø had 10-15% open water, and on 10 July only 40% ice cover remained. This is at least as early as in 2000.

Active layer depth

Development of the active layer (the layer above the permafrost that annually experiences freeze and thaw) were monitored manually throughout the season at two grid-plots, ZEROCALM-1 and ZEROCALM-2. A detailed description of the two sites was given in section 5.1.12 in Meltofte and Thing (1997).

During the 2003 field season all grid points at both sites were re-measured every second week (every week in the early season). Figure 2.10 and 2.11 show the seasonal development in ZEROCALM-1 and ZEROCALM-2, respectively. More than 50 % of the annual thaw occurs within the first two weeks after snow melt in ZEROCALM-1, whereas in ZEROCALM-2 the melt rate is slower, as this site is influenced by a large seasonal snow patch. At the end of the season, on 30 August 2003, the active layer in ZEROCALM-1 reached an average depth of 72 cm and ZEROCALM-2 reached an average depth of 63 cm. For both sites this is the deepest ever measured since 1997 when the grid was established (Table 2.10). The reason must be found in an early snowmelt and a warm and dry summer with mean monthly air temperatures in July and August significantly above normal. Data from the CALM-sites are reported to the circumpolar monitoring programme CALM (Circumpolar Active Layer Monitoring) that is being run by International Permafrost Association.

Soil temperature

At the climate station soil and permafrost temperature is recorded in a profile where sensors are placed in 10 levels below ground (Meltofte and Thing 1996). In 1998 the site was sealed with bentonit pellets in order to prevent seeping of water down the profile. However, data from spring 2003 indicate seeping of water from ground level down to the sensor in 60 cm depth. Reestablishment of the profile is planned to take place in 2004.

The yearly minimum, mean and maximum temperatures for each depth is given in Table 2.11 for the years 1996-2002. The maximum temperature in the different depths do not occur at the same time for the whole profile, as the temperature lower in the profile has a delayed response to the temperature changes above the ground. The same is true for the minimum temperatures. Changes in the minimum temperature from year to year are remarkably higher than the changes in maximum temperature (Table 2.11), reflecting the larger difference in mean air temperature during winter than during summer. Monthly mean temperatures are given in Table 2.12 for the entire 2002 and the first half of 2003.

The grounds start to thaw as soon as the

	0 cm	-2.5 cm	-5 cm	-10 cm	-20 cm	-40 cm	-60 cm	-80 cm	-100 cm	-130 cm
2002										
Jan	-13.1	-12.8	-11.9	-11.2	-12.1	-12.1	-9.7	-8.9	-10.0	-9.3
Feb	-13.6	-13.4	-12.6	-11.9	-12.9	-13.1	-10.8	-10.0	-11.1	-10.4
Mar	-14.4	-13.9	-13.4	-12.3	-13.6	-13.4	-11.3	-10.2	-11.6	-10.8
Apr	-12.7	-	-12.0	-	-12.4	-	-10.9	-	-11.6	-
May	-9.4	-	-9.1	-	-9.9	-	-9.4	-	-10.6	-
Jun	3.5	2.3	2.1	2.6	-0.3	-2.6	-1.6	-2.6	-4.6	-6.5
Jul	9.3	8.0	8.1	8.5	5.6	1.8	2.0	0.5	-1.5	-3.5
Aug	6.1	5.1	5.6	6.2	4.2	1.8	2.6	1.4	-0.7	-2.5
Sept	0.7	0.2	1.0	1.8	0.3	-0.6	1.1	1.0	-0.7	-2.1
Oct	-4.1	-4.1	-2.9	-1.8	-2.3	-2.0	0.3	0.8	-0.9	-2.0
Nov	-14.8	-14.6	-13.6	-12.8	-13.2	-11.8	-7.9	-5.7	-6.6	-5.1
Dec	-13.5	-13.5	-12.7	-11.9	-12.9	-12.6	-9.7	-8.5	-9.5	-8.4
2003										
Jan	-16.2	-15.9	-15.0	-14.2	-14.9	-14.2	-11.2	-9.6	-10.7	-9.6
Feb	-15.1	-15.1	-14.3	-13.6	-14.7	-14.7	-12.2	-11.1	-12.3	-11.3
Mar	-15.3	-15.3	-14.6	-13.8	-14.8	-14.7	-12.2	-11.2	-12.4	-11.6
Apr	-13.8	-13.9	-13.2	-12.5	-13.7	-14.1	-11.9	-11.2	-12.5	-12.0
May	-9.5	-9.7	-8.9	-8.3	-9.7	-10.8	-9.3	-9.2	-10.7	-10.9
Jun	4.2	2.6	2.8	3.0	0.4	-2.5	-1.8	-2.9	-4.9	-6.8
Jul	10.2	8.7	9.0	9.4	6.7	2.7	2.6	0.8	-1.3	-3.4
Aug	7.5	6.3	6.8	7.4	5.3	2.6	3.2	1.7	-0.6	-2.4

Table 2.12. Monthly mean temperatures for different depths below ground in 2002 and first half of 2003.

snow disappears from the ground and the freezing front rapidly moves down to about 80 cm during the fist 2-3 weeks. Then the soil warms up more slowly and in late August/early September the freezing front start to move up again (Figure 2.6).

Temperature in different settings and altitudes

GeoBasis operates a total of 35 TinyTag dataloggers for temperature monitoring in different altitudes and different geomorphological settings in the periglacial landscape of Zackenberg. Positions of sites are given in Table 3.1 in Caning and Rasch 2001 and in Figure 2.1.

All dataloggers were offloaded in 2003 and two loggers were replaced due to operational failures. Annual mean temperatures in the period 1996-2002 are given in Table 2.13. Due to periodic failures it has not been possible to calculate annual statistic for all loggers. However, data exist for large parts of the year for several of these loggers. Daily mean temperatures from the top of Aucella and from Morænebakkerne (site T3 and T1 in Table 2.13) illustrate the temperature variation with altitude during summer 2003 (Figure 2.14).

Break up of the fjord ice on Young Sund

Unprecedented little polar drift ice was found off the coast of Northeast Greenland in autumn 2002, and the new fjord ice on Young Sund broke up a number of times in late autumn. Even on 25 December, the ice broke up to Basaltø during a storm.

When we flew up to Daneborg on 2 June, the edge of fast ice was running northeast from Kap Breusing, and three large open water areas were present between Kap Berghaus, Sandøen and Clavering Ø. In late June, an open water area formed in Young Sund off Zackenbergelven, and during 2-5 July the fjord ice off Zackenbergdalen broke up. On 8 July, the ice in outer Young Sund had broken up and it was possible to go by boat out of the fjord. This is as early as in the exceptionally early season of 2002 (Table 2.9). Also the other fjords in Northeast Greenland broke up very early. Hence, during a flight on 3 July it was seen that most fjords between Scoresby Sund and Young Sund were 20-40% ice-free (Niels Martin Schmidt pers. comm.). No polar drift ice entered Young Sund during the rest of the summer, and the amount of pack ice in autumn off Northeast Green-

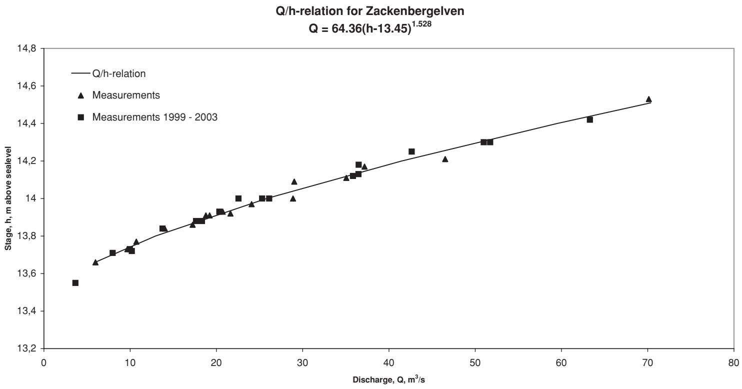


Figure 2.12. Water level – discharge relation curve (Q/h-relation) for Zackenbergelven at the hydrometric station 1995-1998. The coefficient of correlation (R2) for the curve is 0.99. Measurements from the period 1999-2003 indicate that no major changes have occurred to the river profile since 1998.

land was about as limited as in the unprecedented ice-free season of 2002 (see chapter 4.1 in Rasch and Caning 2003). See also section 4.1 for ice in outhermost Young Sund.

2.3 River water discharge and chemistry

Spring break up of Zackenbergelven and secondary streams

Start of running water in the rivulets and Zackenbergelven were among the earliest recorded so far (Table 2.9). Already around

	TinyTag Site	Elevation m a.s.l.	1996 Mean °C	1997 Mean °C	1998 Mean °C	1999 Mean °C	2000 Mean °C	2001 Mean °C	2002 Mean °C
Ground temperature profile	P1								
	0 cm	20	-7.7	-9.8	-9.1	-9.3	-	-	-8.3
	10 cm	20	-	-9.6	-8.8	-8.7	-9.4	-8.7	-7.5
	50 cm	20	-6.7	-9.0	-8.3	-8.3	-9.0	-8.7	-7.8
	118 cm	20	-5.9	-8.1	-7.8	-8.0	-8.1	-8.3	-7.5
Ground temperature profile	P3								
	0 cm	420	-6.2	-9.6	-7.6	-10.5	-8.3	-9.6	-7.6
	10 cm	420	-5.9	-8.6	-	-9.0	-7.5	-9.0	
	66 cm	420	-5.5	-8.7	-	-	-7.4	-8.5	-6.9
Ground temperature profile	P4								
	0 cm	820	-8.5	-10.7	-8.2	-10.9	-	-9.5	-5.7
	10 cm	820	-8.0	-10.5	-8.0	-10.4	-9.2	-9.4	-8.4
	85 cm	820	-7.6	-10.4	-8.6	-9.7	-9.4	-9.5	-8.6
Ground temperature profile	P5								
	0 cm	260	-	-9.2	-	-9.9	-	-9.4	-8.2
	75 cm	260	-	-8.9	-	-9.2	-	-	-7.8
	140 cm	260	-	-8.6	-	-14.8	-	-	-
Ground temperature profile	P6								
	0 cm	11	-	-10.1	-9.5	-8.2	-	-9.1	-7.4
	10 cm	11	-	-9.9	-	-	-	-8.7	-7.2
	30 cm	11	-	-	-	-	-	-9.1	-7.7
	50 cm	11	-	-	-	-	-	-9.1	-7.9
Temperature in snow patch	S1								
	Plateau above	29	-8.1	-	-12.5	-10.0	-10.0	-9.3	-8.5
	Slope high	25	-	-	-5.8	-6.5	-5.3	-5.4	-4.3
	Slope low	23	-5.9	-	-	-	-	-5.5	-4.5
	Plateau below	16	-	-	-8.0	-13.0	-11.7	-9.9	-8.2
Air temperature in Morænebakkerne	T1								
	air, 5 cm	85	-7.3	-9.8	-9.2	-9.8	-10.2	-10.0	-8.9
Air temperature in Store Sødal	T2								
	air, 5 cm	129	-7.9	-10.3	-9.8	-11.1	-10.0	-10.5	-9.3
Air temperature on Aucellabjerg	T3								
	air, 5 cm	965	-9.2	-	-10.2	-	-	-	-
Water temperature in Gadekæret	V2								
	water	35	-10.8	-8.0	-	-	-	-	-6.0

Table 2.13. Annual mean temperatures from TinyTags operated by GeoBasis. Unlike previous reporting, only data from loggers in operation are shown in this table. V1 and P2 were abandoned in 1999 and 2000, respectively, and P6 was replaced in 2000. TinyTags installed in 2002 are operating without problems but are not a part of this table as data from a calendar year has still not been obtained.

30 May, a real stream of water was running in Zackenbergelven past the research station. On 3 June, Kærelv was running, and during the next few days all the rivulets on the slopes of Aucellabjerg began to run. Also this is among the earliest recorded (Table 2.9).

Zackenbergelven

The drainage basin for Zackenbergelven includes Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of 514 km^2. Of these 106 km^2 are covered by glaciers. The hydrometric station is placed at the western bank of the lower part of the river (Meltofte and Thing 1996). In 1998, the hydrometric station was moved to the eastern bank of the river, due to problems with the station being buried beneath a thick snowdrift each winter.

At the hydrometric station (Figure 2.1), water level, water temperature and air temperature are logged automatically every 15 minutes. The water level is measured both by use of a sonic range sensor and by a pressure sensor. At the inspection of the station in august 2003, the sonic range sensor was found to be out of order and was replaced. The discharge data for 2003 is therefore based on data from the pressure sensor. The measured water level is, regardless of the measuring method, recalculated to meter above sea level, which can be transformed to a discharge, using an established relation between water level and discharge (Q/h-relation)

Q/h-relation

Discharges and corresponding water levels have been manually measured by use of a current meter in the field seasons from 1995 to 2003. The function that describes the relation between water level and discharge is shown in Figure 2.12. The Q/h-relation is based on discharge measurements performed in the years 1995 to 1998 at discharges ranging from 5.98 to 70 m^3/s. The high correlation of the data used for the Q/h-relation indicates that the cross profile at the hydrometric station was stable in the period 1995 to 1998. Manual discharge measurements in 1999 to 2003 suggest, that the cross profile was also stable during this period. The Q/h-relation is only valid when the riverbed and riverbanks are free of snow and ice, as snow covering the banks changes the cross profile of the river and ice layers at the bottom of the river gives a false water level.

River water discharge

The water discharge in Zackenbergelven in 2003 is shown in Figure 2.13. From the river starts running until 13 June, the curve is based on manually measured discharges as the riverbed and riverbanks were covered in ice/snow and the Q/h-relation therefore not valid. The total amount of water drained from the catchments area in the season 2003 was *c.* 185 mio. m^3. This amount is on average for Zackenbergelven (Table 2.14). With a drainage area of 514 km^2 this corresponds to an average water loss by drainage of 360 mm from the area. The hydrological year is set to 1 October 2002 -30 September 2003 but data from the climate- and the hydrometric station is only available until 1 September 2003. As the river was still

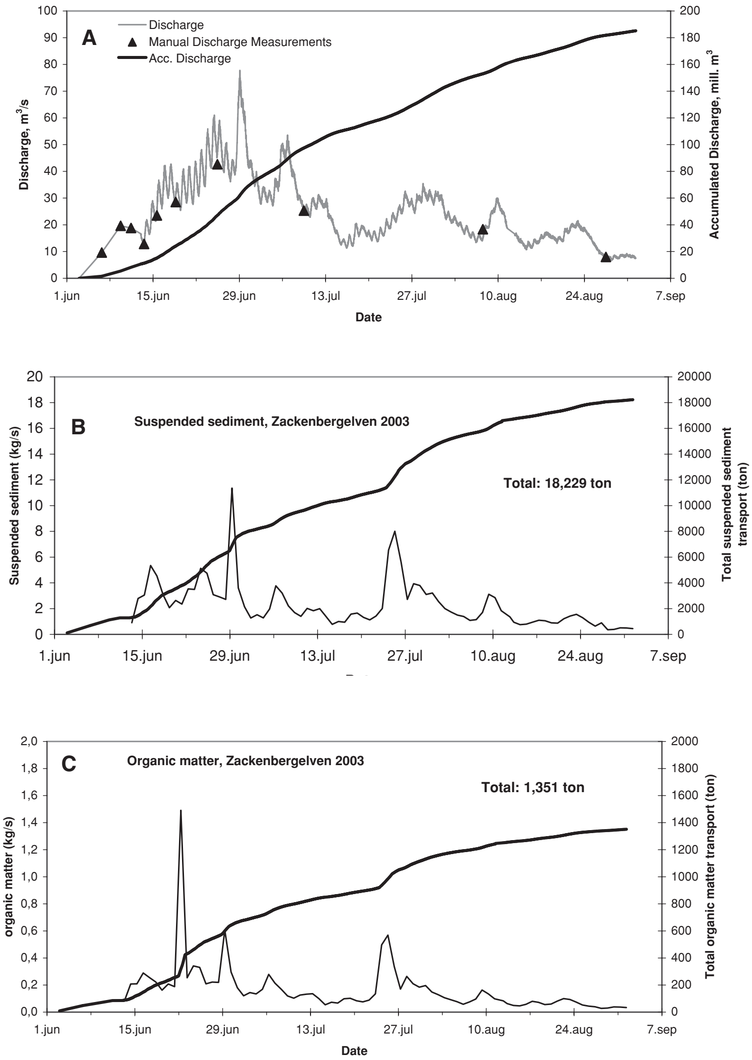


Figure 2.13. Discharges in Zackenbergelven summer 2003. A) River water discharge. B) Suspended sediment concentration and total transport of suspended sediment. C) Suspended organic matter and total transport of organic sediment based on sediment concentration at 08:00 and discharge calculations at 15 minutes interval.

Table 2.14. Total discharge in Zackenbergelven 1996-2003, corresponding water loss for the drainage area (514 km^2) and precipitation measured at the climate station. Data are based on a re-evaluation of raw data and may differ from earlier publications. The re-evaluation includes for example use of the same Q/h-relation (described above) for all discharge data. The hydrological year is set to 1 October - 30 September. 1) Data from 2003 are only available until 1 September.

	1996	1997	1998	1999	2000	2001	2002	2003[1)]
Total Discharge, mill. m^3	124	175	256	180	149	137	306	185
Water loss, mm	241	340	498	350	290	266	595	360
Precipitation, mm	223	140	284	250	170	240	154	186
Total annual transport								
Suspended sediment, ton		29,444	130,133	18,761	16,129	16,883	60,079	18,229
Suspended organic matter, ton		1,643	11,551	2,297	1,247	1,098	3,267	1,351

running when we left the station the total discharge of 2003 is therefore only preliminary. Likewise, the total precipitation in the hydrological year 2003 cannot be reported yet, but 186 mm were recorded at the climate station in the period 1 October 2002 – 1 September 2003 (Table 2.14).

The large difference between measured precipitation and water loss, may partly be cue to changes in the amount of precipitation with altitude and retreat of the glaciers. Furthermore, measurements of precipitation at Zackenberg are connected with great uncertainty. Establishment of a GlacioBasis programme in the future would help to describe the balance of the glaciers and hence limit the uncertainties in the hydrological balance.

Suspended sediment

The hydrological monitoring also includes quantification of suspended solids and organic matter load and characterization of solutes in Zackenbergelven. Variations in suspended sediment and organic matter concentration in relation to water discharge during 2003 are shown in Figure 2.13. Total annual transport of suspended sediment and organic matter from Zackenbergelven 1997-2003 are given in Table 2.14. The estimated total transport is based on concentrations measured in water sampled at 08:00. As the concentration often increases during the day, the total transport is probably underestimated. Results from 1997 indicate, that sediment concentration in Zackenbergelven at 18:00 was on average 30 % higher than concentrations measured at 08:00. To compensate for this problem and to obtain the diurnal fluctuations in suspended sediment concentration, an automatic optical back scatter sensor (OBS) will be installed at the hydrometric station in 2004.

During 2003, the amount of suspended sediment in Zackenbergelven varied from 41-319 mg/l with a mean of 95 mg/l (Figure 2.14). Maximum suspended sediment concentration occurred on 25 July during a warm/sultry period with drizzle. Especially in the tributaries from Aucella and

Suspended sediment (mg/l)

	Store Sødal	Lindeman	Palnatoke	Aucella	Rylekær
7 June	217	337	86	602	2,5
29 June	24	243	425	1638	<2
25 July	69	520	3,777	25,488	dry
14 Aug	69	64	828	4,294	<2

Organic matter as part of total suspended sediment (%)

	Store Sødal	Lindeman	Palnatoke	Aucella	Rylekær
7 June	5	4	9	7	nd
29 June	15	7	7	9	nd
25 July	7	6	6	5	dry
14 Aug	8	10	9	7	nd

Conductivity (uS/cm)

	Store Sødal	Lindeman	Palnatoke	Aucella	Rylekær
7 June	26.1	27.8	29.8	43.6	21
29 June	6.7	34.5	22.6	67.8	37
25 July	7.1	35.7	27.5	135	dry
14 Aug	7.5	77.7	36.9	126.4	46

Table 2.15. Suspended sediment, organic matter in percent of total suspended sediment, and conductivity in water sampled from main tributaries to Zackenbergelven (Store Sødal, Lindeman, Palnatoke, Aucella and Rylekær. On 25 July the stream from Rylekær was dry. nd = not determined.

Palnatoke, extraordinary high sediment concentrations were found on 25 July (Table 2.15). The peak in sediment concentration on 29 June is related to the highest discharge registered in 2003 that happened during 28-29 June. This peak in discharge cannot be ascribed to precipitation events or snow melt in the low land areas and the peak is probably caused by extensive snow melt at the high lying plateaus or release of accumulated melt water in the glaciated part of the drainage basin. Evaluation of air temperatures measured at soil surface in different altitudes, using TinyTag dataloggers (Figure 2.14), reveals that increased sediment concentrations and high water discharges are observed after periods of high temperatures on top of Aucella (965 m a.s.l.). A high correlation is found between the daily mean surface temperature in the elevated areas (illustrated by T3 in Figure 2.14) and the water discharge in Zackenbergelven, using a time difference of two days between temperature and discharge, *i.e.* corresponding to a response time of two days in the system (R^2 =0.83, p<0.001). The correlation is valid for the period 15 June – 16 July. If the rest of the season is included the correlation is less strong. Especially periods when the temperature gradient is inverted (T3>T1 in Figure 2.14) are of interest, as they explain observed increases in water discharge which does not correspond to temperatures measured in the valley. Data from the new micrometeorological station (M3) in 420 m a.s.l. will help to describe these situations in more detail.

Suspended sediment contained between 5 and 12% organic matter with an average of 7% (determined by loss on ignition (L.O.I.). Additional samples of suspended sediment were analysed for organic C and organic N at National Environmental Research Institute. The ratio of carbon to nitrogen (C/N-ratio) ranges between 15 and 40 during most of the season, reflecting a common C/N range for soil and plant material in the area (Figure 2.14). During the first half of August a pronounced peak with C/N values up to 100, illustrates a change in source of organic material. Less decomposable organic material with a higher C/N (lower nutrient status) could originate from newly exposed soil layers underneath snow patches or from lateral drainage of soil water from an increasing active layer.

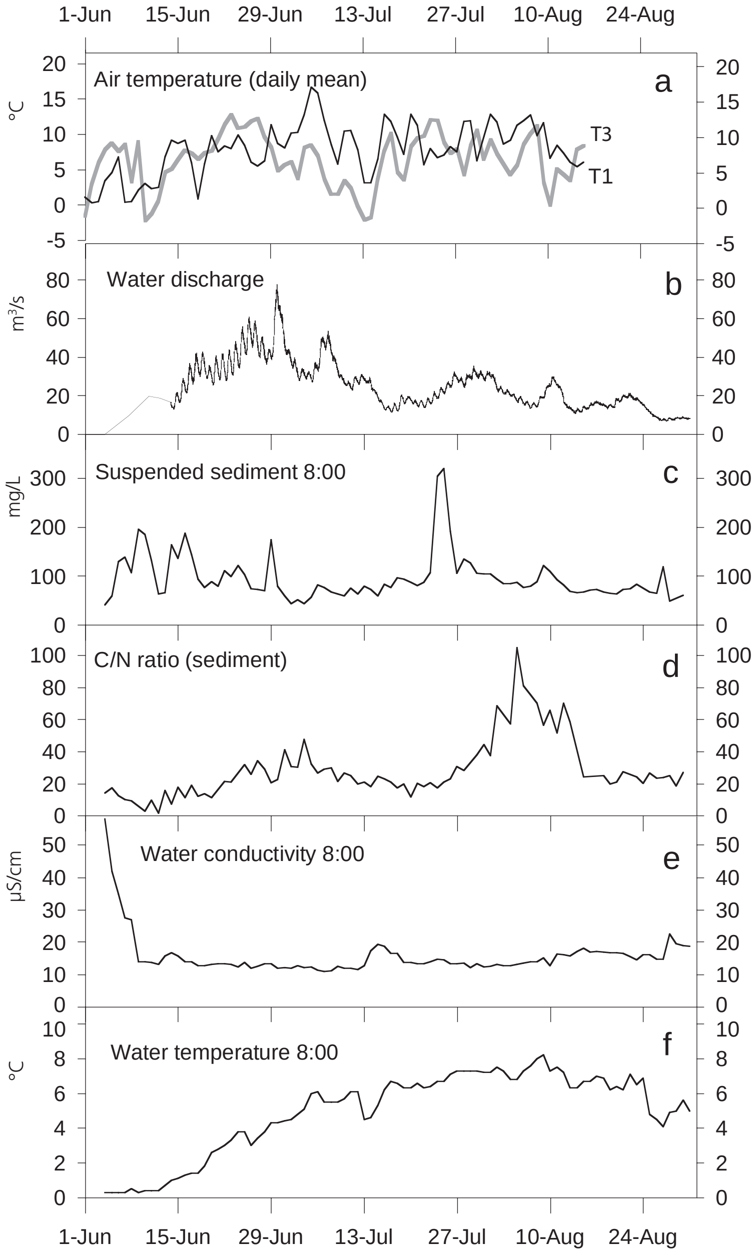


Figure 2.14. Climatic parameters in Zackenbergelven 2003. a) Daily mean air temperatures at soil surface on top of Aucella (965 m a.s.l.) and in the valley (85 m a.s.l) from TinyTag temperature measurements (Site T1 and T3 in Table 2.13). b) Water discharge. c) Concentration of suspended sediment. d) C/N-relation in suspended sediment. e) Conductivity. f) Water temperature. Discharge is measured every 15 minutes, whereas all other curves are based on daily measurements performed at 08:00.

River water chemistry

Water was sampled from Zackenbergelven near the hydrometric station every morning at 08:00. Conductivity, water temperature, pH and alkalinity of the river water were measured in Zackenberg and chemical analyses of solute concentrations (Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Al^{3+}, Mn^{3+}, Cl^-, NO_3^{2-}, SO_4^{2-}) were carried out at Institute of Geography, University of Copenhagen.

Daily variations in conductivity and water temperature in Zackenbergelven are shown in Figure 2.14. The high conductivity during the first days with discharge indicates high dissolved load concentrations in the first melt water. This phenomenon has earlier been ascribed to solutes being washed out of the snow package during the first snow melt (section 3.3 in Rasch and Caning, 2003). Except from this pulse (occurring between 3 and 8 June), concentrations of solutes are fairly constant over the season and the conductivity in the river water ranges between 12 and 20 μS/cm.

Suspended sediment and solutes in tributaries to Zackenbergelven

Regular sampling of water from the main tributaries to Zackenbergelven (Store Sødal, Lindeman, Palnatoke, Aucella, and Rylekær) has now been incorporated in the monitoring programme. In 2003, water was sampled four times during summer from these tributaries. Locations of sample sites are given in Figure 2.1. Water temperature and conductivity were measured on location, whereas water chemistry, suspended sediment and organic matter concentration were determined from water samples.

Low conductivity and low suspended sediment concentrations characterize water from Store Sødal, whereas water from the Aucella tributary is characterized by

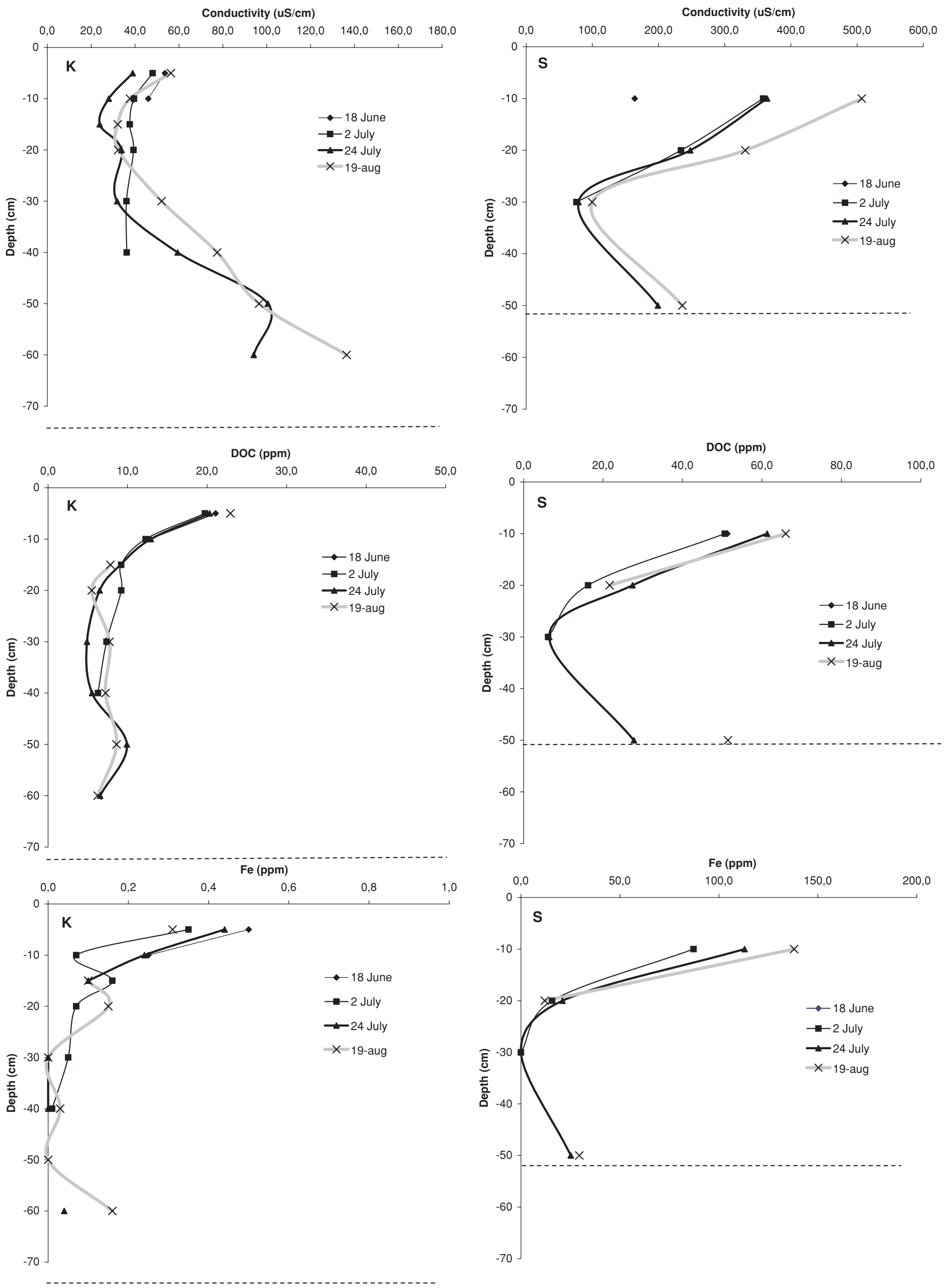


Figure 2.15. Conductivity, DOC, and Fe2+ in soil water from a well-drained Cassiope heath (K) shown left and from a Sphagnum-Eriophorum dominated wetland (S) shown right. Maximum active layer depth (14 August 2003) was 78 cm in K and 52 cm in S. Notice different scales on x-axes.

high suspended sediment concentrations and high conductivity (Table 2.15). Organic matter (determined by loss on ignition L.O.I) accounts for 4-15% of the total suspended sediment without any significant variation between the tributaries (Table 2.15). The chemistry and amount of suspended matter reflects the different geology of the drainage basins. Store Sødal is fed mainly by glaciers and melt water from snow that passes bedrock dominated by gneissic parent material. Palnatoke and Aucella tributaries are fed by snow melt water that passes easily erodible sediments. Due to the relative contribution of water from the different tributaries, Store Sødal >> Lindeman > Palnatoke > Aucella > Rylekær, the pattern from Store Sødal dominates in Zackenbergelven.

2.4 Precipitation and soil water chemistry

Precipitation

During the 2003 season, water from an open precipitation collector were sampled after arrival for a bulk sample of the winter precipitation, and again on 9 July, 15 July and 11 August after rain-events. Conductivity and pH were measured in Zackenberg and filtered sub samples were analysed for total concentration of Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Al^{3+}, Mn^{3+}, Cl^-, NO_3^{2-}, SO_4^{2-} at Institute of Geography, University of Copenhagen. Rain water had pH around 4.5 and conductivity of 10-40 μS/cm. Compared to the soil water, precipitation is relatively dilute in solutes. The dominating ions are Na^+, Cl^- and SO_4^{2-} which all have a marine origin.

Soil water

Since 1996, soil water has been sampled from various depths in the active layer and chemical composition of the soil water has been monitored. In 2003 the soil water monitoring programme was expanded as three new sites were installed in order to observe variations in soil water nutrient status between soils covered by different plant communities. New sites were installed next to BioBasis plant phenology plots, *i.e.* in a dry soil covered by *Dryas* heath (Dry-site, UTM: 8265045 mN, 513816 mE), in a typical *Salix* snowbed vegetation (Sal-site, UTM: 8264692 mN, 513623 mE) and in a well-drained soil covered by a mixed heath vegetation (Mix-site, UTM: 8264348 mN, 513567 mE). Water is extracted from the soil using suction cup lysimeters from Prenart („Prenart Super Quartz"made of porous PTFE (teflon) and quartz) installed 5 and 10 cm below the soil surface in order to describe water in the root zone, and 30 cm below the soil surface in order to describe water below the root zone. All sites has been equipped with soil moisture sensors (ThetaProbe, Type ML2x) placed 5, 10 and 30 cm below the soil surface and temperature sensors (TinyTag, Gemini Dataloggers) placed 0, 10 and 30 cm below the surface. Due to soil disturbance caused by installation, water will not be sampled from these plots before 2004.

The two original sites are situated in a wet soil dominated by *Sphagnum-Eriophorum* (S-site) just south of ZEROCALM-2, and in a well-drained *Cassiope* heath (K-site) near the climate station. A more detailed description of these sites are given in Caning and Rasch (2000) and Rasch and Caning (2003). From these profiles, water was sampled four times during summer 2003. Alkalinity, pH and conductivity were measured in Zackenberg and analysis of dissolved Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Al^{3+}, Mn^{3+}, Cl^-, NO_3^{2-} and SO_4^{2-} were carried out at Institute of Geography, University of Copenhagen. Furthermore, water was analysed for NH_4^+, DOC and DON at Botanical Institute, University of Copenhagen and these analyses will now be incorporated in the monitoring programme.

Chemical composition of soil water from the two main sites (S and K) show distinct variation with depth and between sites. The total concentration of solutes (0-20 cm) is almost ten times as high in the grassland (S) than in the heath (K), which is reflected in the conductivity of the soil water shown in Figure 2.15. The variation in total solute concentrations between the two sites corresponds to the release of nutrient expected from the decomposability of the plant material. *Cassiope* with evergreen leaves and woody stems has a lower substrate quality and a slower decomposition rate than the wetland vegetation.

In Figure 2.15 dissolved organic carbon (DOC) illustrate that organic acids resulting from decomposition of organic material causes a weak acidification in the top soil at both sites (pH between 5 and 6) and thereby cation exchange becomes impor-

Table 2.16. Summary of summer season environmental variables and CO2 exchange 2000-2003.

	2000	2001	2002	2003
Beginning of growing season	25 June	6 July	2 July	28 June
End of growing season	11 August	18 August	16 August	20 August
Length of growing season	47	43	45	53
Beginning of measuring season	6 June	8 June	3 June	5 June
End of measuring season	25 August	25 August	25 August	30 August
Length of measuring season	81 days	81 days	86 days	86 days
NEE for growing season (g C m^2)	(-) 22.7	(-) 19.1	(-) 18.2	(-) 30.4
NEE for whole measuring season (g C m^2)	(-) 19.1	(-) 8.7	(-) 9.5	(-) 23
Maximum daily C accumulation (g C m$^{÷2}$ d$^{÷1}$)	(-) 0.92	(-) 0.94	(-) 1.00	(-) 1.4

tant as acid consuming processes in the soil profiles.

Due to impeded vertical drainage caused by a thin active layer and continous suply of meltwater from the nearby snow patch, the S-site represents a reduced environment, where iron is found in high concentrations as Fe^{2+}, whereas the well-drained K-site with a deeper active layer, represents an oxidizing environment where iron in solution is almost absent (Figure 2.15).

The maximum active layer depth measured 14 August was 52 cm at the S-site and 78 cm at the K-site. At both sites, concentration of solutes increases near the permafrost table as solutes are leached below the root zone and excluded from the ice. In contrast to pure water, no unique freezing point exists for soil water. Solutes in the water lower the freezing point, and in addition, when soil water freezes the solutes are concentrated near the freezing front due to exclusions from the ice (Williams *et al.* 1989).

Seasonal variations are observed at both plots. At the S-site conductivity in the top soil increases from 150 to 500 μS/cm in the period from soil thaw to the end of the season. Several effects may contribute to this enhanced concentration, *i.e.* evaporation of water and thereby concentration of dissolved elements, decomposition of organic material due to increased biological activity when the temperature increases during summer and dilution early in the season by melt water from snowpatches upstreams. Later in the season meltwater from snowpatches is chemically enriched from overland flow and lateral drainage in the soil.

At the well-drained K-site the conductivity decreases in the top soil during the first month of the season, reflecting that decomposition rates are exceeded by plant uptake and leaching.

2.5 Carbon dioxide flux

Since 2000, measurements of carbon dioxide exchange have been conducted at the micrometeorological station (M1) located *c.* 150 m north of the climate station. The carbon flux has been obtained by the use of the eddy correlation technique (section 4.2 in Rasch and Caning 2003).

Figure 2.16 shows daily variation in carbon flux and temperature, during nearly three months of continuous measurements. The sign convention used is standard for micrometeorological measurements, *i.e.* fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative. The flux is a net value representing the sum of the uptake of CO_2 by plants from the photosynthesis and the loss of CO_2 due to microbial decomposition in the soil, *i.e.* respiration. Assimilation of CO_2 is dependent of climatic conditions, mainly solar radiation, and the type and amount of vegetation. The soil respiration process is mainly governed by the soil temperature. The sum of the above mentioned processes is also denoted Net Ecosystem Exchange (NEE), and is expressed in g C per m^2 per day.

During the summer 2003 measurements were conducted continuously from 5 June to 30 August. During this period the seasonal variation in the fluxes may be divided into three characteristic periods controlled by abiotic factors: late winter, summer and autumn.

The late winter period had daily air temperatures fluctuating around 0°C and daily carbon fluxes above zero. During this period, the heath surface was a source of CO_2, *i.e.* the respiration exceeded the photosynthesis. Until 14 June, the very small fluxes directed from the surface to the atmosphere reflected that carbon dioxide was trapped under the snow. By 15

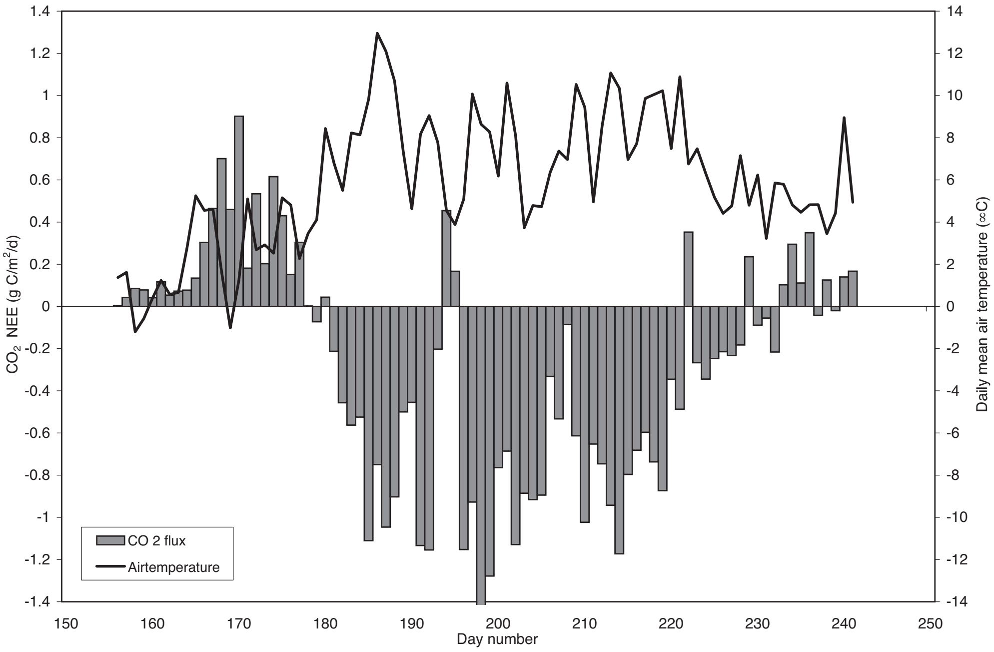


Figure 2.16. Temporal variation in Net Ecosystem Exchange (NEE) and daily mean air temperature at the heath in 2003.

June a disintegration of the snow pack caused the fluxes to increase, allowing sunlight to heat the surface and respiration to increase. The loss of CO_2 continued until 26 June.

Once the snow had melted the summer season began. During the summer period the photosynthesis exceeded the respiration and CO_2 accumulated. From 28 June, net carbon dioxide accumulation turned the heath surface from a source of carbon dioxide to a sink. The onset of CO_2 accumulation is correlated with the relatively high air temperatures from 29 June, where daily mean air temperatures increased to 8°C. On a few occasions of poor weather in mid July the respiration exceeded the photosynthesis and reversed the CO_2 flux, and the ecosystem changed from sink to source. A maximum daily C accumulation of 1.4 g C per m^2 was found on 17 July. This is far above the maximum range of 0.9 – 1.0 g C per m^2 measured in 2000-2002 (Table 2.15) and must be explained by a foehn situation where the strong warm wind caused temperatures to rise late in the evening. On 17 July at 23:00 a temperature of 17°C was measured, which turned out to be the highest temperature of the season

From 21 August, the flux reversed and the surface became a net source of CO_2. Air temperature and light available for photosynthesis decreased, but the soil was still warm (4-5°C in 2.5 cm) and the period was characterized by respiration exceeding photosynthesis.

The total accumulation during the three months of monitoring amounts to 23 g C per m^2. This is the largest accumulation registered during the four years of measurements in Zackenberg (Table 2.15). Compared to previous years, 2003 had the longest season with net carbon accumulation, starting at 28 June and lasting until 20 August. A long season combined with favourable climatic conditions during the plant growth phase caused the high accumulation.

Like in previous years data acquisition was very stable throughout the field season. In total this season provided more than 2000 hours of measurements and only 3% were lost due to calibration, maintenance or malfunctioning of the equipment.

2.6 Geomorphology

Landscape monitoring based on photos of different dynamic landforms such as talus slopes, rock glaciers, mud slides, frost

	Recession (m)			
	Site 1	**Site 2**	**Site 3**	**Site 4**
1996-1997	0	0	0.3	1
1996-1998	0	0	0.3	1.3
1996-1999	0	0	0.3	1.3
1996-2000	0	0	0.5	1.4
1996-2001	0	0	0.5	1.4
1996-2002	0	0	0.7	2.8
1996-2003	0	0.4	1.6	3.2

Table 2.17. Cumulated coastal cliff recession at the southern coast of Zackenbergdalen 1996-2003.

Figure 2.17. Location of GeoBasis monitoring sites along the southern shore of Zackenbergdalen.

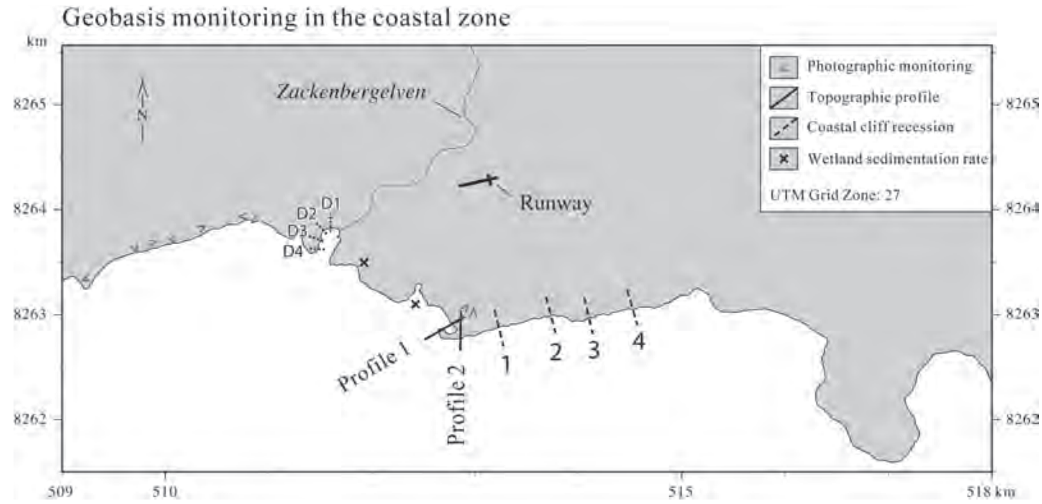
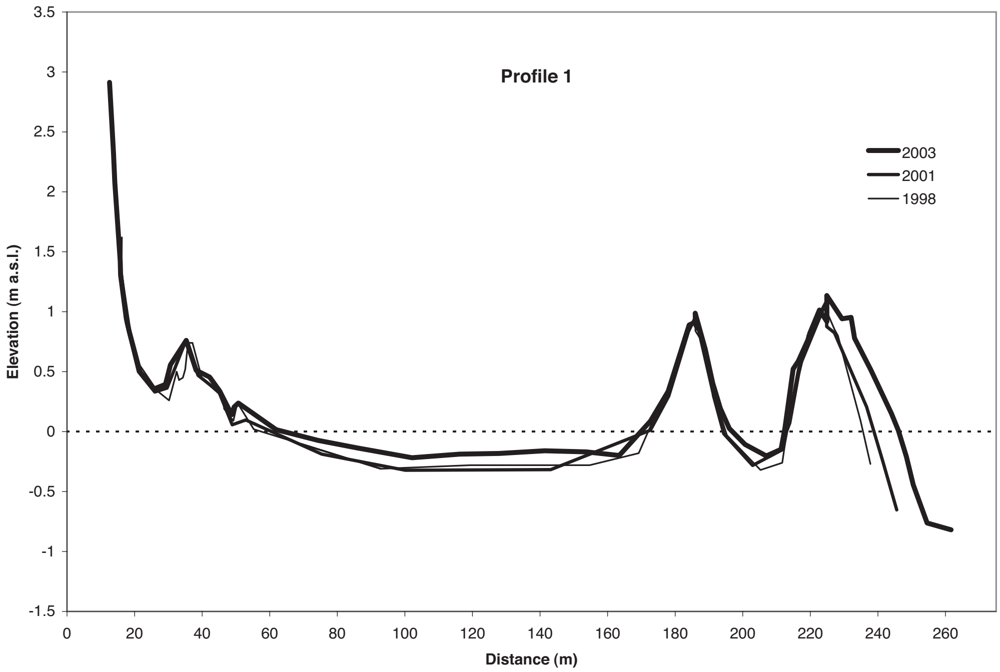


Figure 2.18. Profile 1. Comparison of cross shore profiles from 1998, 2001 and 2003. Notice the different scales on axes.



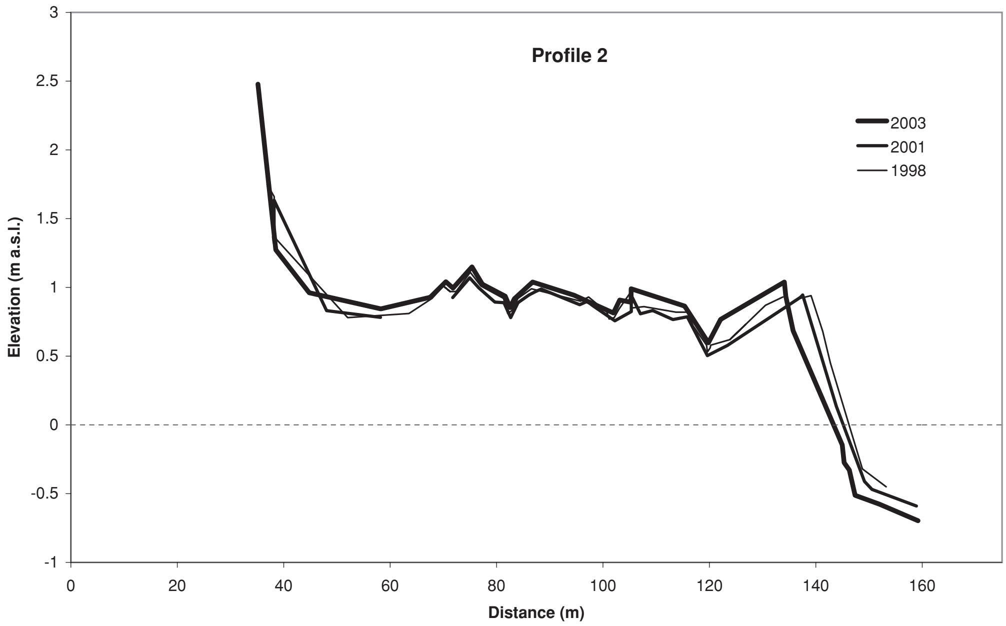


Figure 2.19. Profile 2. Comparison of cross shore profiles from 1998, 2001 and 2003. Notice the different scales on axes.

boils, gullies, thermokarsts, beach ridges, coastal cliffs, snow patches and ice wedges are part of the monitoring. In total 21 out of 24 photos were repeated in 2003. In the future all photos will be captured by digital camera and old photos in the GeoBasis archive will be scanned so that all photos will become available in a digital format.

Ice wedge growth rate and salt marsh accretion were not measured in 2003. The dynamics of these landforms are measured at intervals of 5-10 year. Next measurement is scheduled in 2004.

Coastal geomorphology

Coastal monitoring in Zackenberg comprises measurements of morphological changes at two cross shore profiles at a coastal spit, recurrent photography of dynamic coastal landscape features, measurements of coastal cliff retreat rates and measurements of vertical accretion of salt marsh. Locations of the coastal monitoring sites are given in Figure 2.17.

Results of the cliff recession measurements along the southern coast of Zackenbergdalen from 1996-2003 are given in Table 2.17. At three out of four sites the coastal cliff had recessed significant between 2002 and 2003 and the retreat rates indicate that the process has speeded up the last two years. This is probably related to the low extent of sea ice outside Northeast Greenland, which has been observed in the last two years. The ice has a dampening effect on the swell and therefore reduces the impact of waves on the shore.

Data on the coastal retreat rates in Zackenberg are reported to the ACD (Arctic Coastal Dynamics) monitoring network and will be incorporated in their database.

Cross shore profiles

In 2003 two topographic cross shore profiles at a re-curved spit near the old delta were re-surveyed. Location of the profiles, Profile 1 and Profile 2, are shown in Figure 2.17. Profiles measured in 2003 are compared to the profiles from 1998 and 2001 in Figure 2.18 and 2.19. At Profile 1, some sedimentation has taken place since 2001 and the outer shoreline has moved 5-10 m seawards. In the lagoon up to 10 cm of sedimentation has taken place during the last two years. In contrast some erosion has taken place at Profile 2, and the shoreline has moved 2-4 m landwards during the last 5 years. It seems, like the observed increased erosion along the shoreline (observed as cliff recession in Table 2.17) especially during the last two years, is a source of sediment for the sedimentation at the re-curved spit. Figure 3.4.13.2 in Meltofte and Thing 1997 and Figure 3.11 in Rasch 1999 reveal, that no significant horizontal or vertical changes were observed from 1991-1998.

Block slumping in the Zackenberg river delta

Four profile lines at the coastal cliff west of the Zackenbergelven river delta were established in August 2000 (Figure 2.17). No significant changes were observed when the sites were inspected in 2001 but at the re-survey in 2003 extensive erosion rates were observed due to river water excavating the western river bank. In the period from 2000 to 2003 the eastern part of the cliff facing the delta recessed more than 25 m due to massive block slumping as described in section 3.4 Caning and Rasch (2001). Exactly how many meters the cliff has recessed at site D3 and D4 cannot be determined, as pegs marking the profile line has been removed with the sediment.

A rough estimate of the amount of material washed out in the fjord due to block slumping at this site since 2000, results in more than 50,000 tons of sediment. In the same period app. 95,000 tons of suspended sediment was washed out from Zackenbergelven (Table 2.14). The plateau above the cliff appears heavily crevassed and there is an ongoing supply of material to the delta from slides. Near site D1 the soil has collapsed and formation of a thermokarst erosion gully is taking place.

3 Zackenberg Basic: The BioBasis programme

Hans Meltofte (ed.)

The BioBasis programme at Zackenberg is carried out by the National Environmental Research Institute (NERI), Department of Arctic Environment, Ministry of Environment, Denmark. It is funded by the Danish Environmental Protection Agency as part of the environmental support programme Dancea – Danish Cooperation for Environment in the Arctic. The authors are solely responsible for all results and conclusions presented in the report, and they do not necessarily reflect the position of the Danish Environmental Protection Agency.

Details on BioBasis methods and sampling procedures are presented in a manual (Meltofte and Berg 2003), which is available from the Zackenberg home page (http://www.zackenberg.dk). A map with locality names used in this chapter is found at the same place. Also, a synopsis of the entire BioBasis programme and primary data are presented on the website.

3.1 Vegetation

Hans Meltofte and Line Anker Kyhn

The weekly records on amounts and phenology of flowering were made by Line

Plot	1996	1997	1998	1999	2000	2001	2002	2003
Cassiope 1	14.6	9.6	13.6	27.6	2.6	7.6	13.6	6.6
Cassiope 2	19.6	21.6	27.6	4.7	<4.6	21.6	20.6	13.6
Cassiope 3	15.6	21.6	20.6	3.7	13.6	20.6	20.6	7.6
Cassiope 4	20.6	15.6	20.6	4.7	13.6	21.6	17.6	7.6
Dryas 1	<3.6	<27.5	(23.5)	6.6	<4.6	<31.5	<30.5	4.6
Dryas 2	26.6	27.6	4.7	12.7	21.6	3.7	28.6	22.6
Dryas 3	6.6	<27.5	7.6	19.6	<4.6	6.6	6.6	6.6
Dryas 4	1.6	3.6	13.6	21.6	<4.6	7.6	6.6	(31.5)
Dryas 5	6.6	31.5	4.6	14.6	<4.6	5.6	6.6	6.6
Dryas 6	21.6	4.7	5.7	11.7	20.6	28.6	30.6	19.6
Papaver 1	20.6	18.6	21.6	3.7	1.6	20.6	18.6	12.6
Papaver 2	20.6	20.6	21.6	4.7	14.6	21.6	20.6	21.6
Papaver 3	21.6	15.6	20.6	3.7	13.6	21.6	19.6	14.6
Papaver 4	21.6	4.7	5.7	11.7	20.6	27.6	30.6	19.6
Salix 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5	(31.5)
Salix 2	14.6	20.6	23.6	1.7	13.6	21.6	14.6	14.6
Salix 3	7.6	8.6	12.6	24.6	<3.6	7.6	7.6	(2.6)
Salix 4	20.6	5.6	21.6	22.6	7.6	11.6	10.6	13.6
Salix 5	20.6	20.6	21.6	4.7	14.6	21.6	20.7	21.6
Saxifraga 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5	(1.6)
Saxifraga 2	<3.6	<27.5	<27.5	(27.5)	<3.6	<31.5	<30.5	(31.5)
Saxifraga 3	-	<27.5	27.5	6.6	<3.6	(27.5)	<30.5	(1.6)
Silene 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5	(1.6)
Silene 2	<3.6	<27.5	<27.5	(27.5)	<3.6	<31.5	<30.5	(31.5)
Silene 3	-	<27.5	27.5	6.6	<3.6	(27.5)	<30.5	(1.6)
Silene 4	24.6	28.6	20.6	6.7	21.6	28.6	25.6	19.6

Table 3.1. Inter- and extrapolated dates of 50% snow cover for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis *plots 1996-2003. Brackets denote extrapolated dates.*

Anker Kyhn during the entire season. This year, three new *Salix arctica* plots were established in relatively snow rich habitats. Salix 5 is the same area as Papaver 2, and Salix 7 the same as Dryas 2, while Salix 6 is an entirely new plot.

To prevent confusion, the numbering on the lower part of the ZERO-line (nos -1 – -65) was reversed this year, so that all numbers run from peg no. 1 at the coast to 155 at he summit of Aucellabjerg. In the datasheets from 1992 and 2000, both the revised and the original numbering is given. New pegs were established on vegetation borders between nos 61 and 63 (old nos -4 and -2, respectively) and above no. 105, which were snow covered during establishment of the line in 1992, 1994 and 2000. Furthermore, aluminium tubes were established at two metre intervals between nos 61 and 63, and between nos 104-106 in the same way as on the rest of the line (see chapter 4.1 in Caning and Rasch 2001).

Reproductive phenology, amounts of flowering and berry production

Due to the extensive snow cover in early spring, some of the flower plots that are free from snow in most years such as Dryas 1, Salix 1 and Saxifraga/Silene 1 and 2, did not clear until around 1 June (Table 3.1). On the other hand, the fast snowmelt during June resulted in very early clearance of otherwise late plots such as Cassiope 3 and 4, Dryas 2, 4 and 6, Papaver 3 and 4 and Silene 4. Some of these even cleared earlier than recorded before.

The result of the late snowmelt in the otherwise early snow free plots was that flowering here was among the latest recorded (Table 3.2) – and *vice versa* that the fast snow melt in combination with high temperatures in June resulted in very early flowering in the otherwise late snow free plots. Hence, flowering in the *Cassiope* plots together with Dryas 2 and 6, Papaver 2 and Silene 4 was the earliest recorded so

Plot	1996	1997	1998	1999	2000	2001	2002	2003
Cassiope 1	2.7	6.7	6.7	13.7	(28.6)	4.7	3.7	27.6
Cassiope 2	6.7	20.7	(21.7)	(26.7)	-	12.7	7.7	3.7
Cassiope 3	9.7	18.7	(19.7)	(26.7)	-	11.7	9.7	2.7
Cassiope 4	15.7	15.7	(21.7)	(26.7)	-	19.7	7.7	5.7
Dryas 1	19.6	22.6	26.6	3.7	26.6	22.6	25.6	30.6
Dryas 2	13.7	4.8	8.8	-	24.7	1.8	29.7	19.7
Dryas 3	2.7	26.6	6.7	13.7	27.6	6.7	28.6	29.6
Dryas 4	27.6	6.7	(9.7)	14.7	26.6	6.7	28.6	23.6
Dryas 5	30.6	5.7	1.7	7.7	22.6	5.7	28.6	28.6
Dryas 6	19.7	9.8	(7.8)	19.8	21.7	29.7	1.8	17.7
Papaver 1	14.7	20.7	24.7	2.8	4.7	12.7	12.7	5.7
Papaver 2	14.7	23.7	26.7	30.7	15.7	14.7	13.7	8.7
Papaver 3	14.7	19.7	26.7	1.8	10.7	17.7	13.7	11.7
Papaver 4	15.7	7.8	11.8	15.8	(20.7)	(27.7)	2.8	17.7
Salix 1	6.6	6.6	12.6	14.6	11.6	8.6	9.6	17.6
Salix 2	21.6	29.6	10.7	17.7	28.6	29.6	28.6	28.6
Salix 3	20.6	25.6	(28.6)	5.7	11.6	24.6	16.6	15.6
Salix 4	29.6	23.6	2.7	3.7	17.6	28.6	26.6	23.6
Salix 5								5.7
Saxifraga 1	-	31.5	5.6	7.6	6.6	8.6	3.6	14.6
Saxifraga 2	-	2.6	7.6	14.6	9.6	8.6	6.6	14.6
Saxifraga 3	5.6	1.6	9.6	16.6	7.6	9.6	7.6	14.6
Silene 1	20.6	24.6	21.6	28.6	26.6	28.6	23.6	1.7
Silene 2	23.6	29.6	1.7	30.6	2.7	30.6	27.6	4.7
Silene 3	30.6	26.6	23.6	6.7	28.6	4.7	28.6	4.7
Silene 4	26.7	10.8	20.8	-	28.7	29.7	28.7	20.7

Table 3.2. Inter- and extrapolated dates of 50% open flowers (50/50 ratio of buds/open flowers) for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis *1996-2003. Brackets denote interpolated dates based on less than 50 buds + flowers.*

Table 3.3. Inter- and extrapolated dates of 50% open seed capsules for arctic poppy Papaver radicatum, arctic willow Salix arctica and purple saxifrage Saxifraga oppositifolia 1995-2003. Brackets denote interpolated dates based on less than 50 flowers + open capsules.

Plot	1995	1996	1997	1998	1999	2000	2001	2002	2003
Papaver 1	5.8	15.8	-	30.8	>26.8	9.8	16.8	20.8	1.8
Papaver 2	15.8	15.8	24.8	-	>26.8	(17.8)	16.8	17.8	3.8
Papaver 3	6.8	13.8	19.8	-	29.8	14.8	18.8	20.8	6.8
Papaver 4	20.8	-	>27.8	-	(>26.8)	(16.8)	24.8	(26.8)	10.8
Salix 1	8.8	8.8	8.8	5.8	13.8	12.8	2.8	29.7	2.8
Salix 2	12.8	9.8	19.8	30.8	25.8	20.8	18.8	11.8	3.8
Salix 3	2.8	8.8	16.8	(19.8)	16.8	12.8	14.8	5.8	28.7
Salix 4	12.8	17.8	14.8	21.8	16.8	13.8	13.8	12.8	3.8
Salix 5	-	-	-	-	-	-	-	-	4.8
Salix 6	-	-	-	-	-	-	-	-	11.8
Salix 7	-	-	-	-	-	-	-	-	13.8
Saxifraga 1	-	20.7	10.8	11.8	13.8	9.8	8.8	4.8	7.8
Saxifraga 2	-	23.7	16.8	24.8	15.8	15.8	14.8	1.8	1.8
Saxifraga 3	-	7.8	9.8	23.8	16.8	7.8	13.8	12.8	9.8

far. Late snowmelt in the otherwise early *Saxifraga* plots even impacted opening of the seed capsules, so that seeds were exposed later than or close to average (Table 3.3) in spite of the exceptionally warm summer. In contrast, exposure of seeds in most *Papaver* and *Salix* plots was earlier than recorded before, *i.e.* as much as 17-29 days earlier than in the latest years. Only the normally snow free Salix 1 plot was not exceptionally early, but still developed as early as in other early years.

2003 was again a year of many flowers, but most were within the range from previous years (Table 3.4). Especially Salix 1 and 4 together with Silene 3 and 4 and *Eriophorum scheuchzeri* 1 stand out with significantly more flowers than before. The large numbers of flowers may be related to a favourable summer in 2002, since these plants develop their flower buds the year before flowering (Mølgaard *et al*. 2002).

Only one female arctic willow pod in our *Salix* plots was infested by fungus this year (Table 3.5).

Relatively large numbers of bearberries *Arctostaphylos alpina* were produced in 2003 (Table 3.6), but the number of berries only made up 4-20% of the flowers recorded in the plots (see Table 3.4). Berry production was even poorer in the arctic blueberry *Vaccinium uliginosum* plot, where only 0.15% of the huge number of flowers resulted in a berry. However, besides the berries stated, 42 undeveloped 'mini-berries' were recorded in the plot, and large numbers of blueberries were found in other areas. Crowberries *Empetrum nigrum* appeared in even larger numbers than recorded earlier.

Vegetation greening in flower study plots

Unfortunately, no satellite images were available for regional NDVI analyses around 1 August this year.

Based on handheld RVI meter measurements, 2003 was an early growth season in most plant communities. Except for *Cassiope tetragona*, which often has a 'flat' and late culmination, greening in most study plots peaked around 15-22 July (Table 3.7). This is the earliest culmination recorded so far, and it may be related to the very warm and sunny June and July. The level of greening was generally a bit higher than in the two previous years, but a little lower than 1999 and 2000. This is even more pronounced for the *Salix arctica* plots, if the new 'snow bed' plot (Salix 6) is excluded, giving a *Salix* mean of 0.47.

3.2 Arthropods

Mogens Lind Jørgensen and Hans Meltofte

As usual, two window traps and five pitfall trap stations with eight yellow traps in each were operated during the 2003 season, and procedures were concurrent with preceding years. Line A. Kyhn performed the sampling of arthropods, and Mogens Lind Jørgensen sorted the samples. All

Plot	Area	1995	1996	1997	1998	1999	2000	2001	2002	2003
Cassiope 1	2	1321	1386	1855	322	312	28	1711	1510	851
Cassiope 2	3		1759	550	19	16	8	1353	952	1001
Cassiope 3	2	256	844	789	35	18	0	771	449	817
Cassiope 4	3	456	1789	391	24	6	3	578	164	1189
Cassiope 5	2.5	-	-	1224	455	474	50	3214	3208	2708
Cassiope 6	2	-	-	>350	16	3	1	544	736	134
Dryas 1	4	(936)	(797)	138	223	852	607	1016	627	744
Dryas 2	60	534	1073	230	42	49	46	172	290	552
Dryas 3	2	603	522	123	255	437	266	577	235	294
Dryas 4	6	(325)	(164)	155	69	356	55	301	187	224
Dryas 5	6	(654)	(504)	123	191	655	312	506	268	589
Dryas 6	91	809	1406	691	10	25	140	550	430	627
Dryas 7	12	-	-	787	581	1355	574	1340	1483	1543
Dryas 8	12	-	-	391	240	798	170	403	486	545
Papaver 1	105	302	337	265	190	220	197	237	277	278
Papaver 2	150	814	545	848	316	315	236	466	456	564
Papaver 3	90	334	238	289	266	183	240	259	301	351
Papaver 4	91	196	169	192	80	30	35	65	59	56
Salix 1 mm.	60	-	807	959	63	954	681	536	1454	1931
Salix 1 ff.	-	520	1096	1349	149	1207	900	1047	1498	2159
Salix 2 mm.	300	-	790	1082	132	416	55	803	1206	967
Salix 2 ff.	-	617	1376	1909	455	418	95	1304	1816	1638
Salix 3 mm.	36	239	479	412	32	52	330	1196	344	621
Salix 3 ff.	-	253	268	237	38	68	137	1009	315	333
Salix 4 mm.	150	-	1314	831	509	718	965	680	1589	1751
Salix 4 ff.		1073	1145	642	709	880	796	858	1308	1418
Salix 5 mm.	-	-	-	-	-	-	-	-	-	494
Salix 5 ff.	-	-	-	-	-	-	-	-	-	371
Salix 6 mm.	-	-	-	-	-	-	-	-	-	-
Salix 6 ff.	-	-	-	-	-	-	-	-	-	1145
Salix 7 mm.	-	-	-	-	-	-	-	-	-	612
Salix 7 ff.	-	-	-	-	-	-	-	-	-	839
Saxifraga 1	7	-	(1010)	141	163	584	1552	558	542	1213
Saxifraga 2	6	-	513	387	432	158	387	515	617	561
Saxifraga 3	10	-	529	322	288	707	403	558	318	509
Silene 1	7	-	(251)	403	437	993	1327	674	766	1191
Silene 2	6	-	493	524	440	400	692	568	1094	917
Silene 3	10	-	348	211	127	313	274	348	480	1000
Silene 4	1	466	270	493	312	275	358	462	470	794
E. scheuz. 1	10	-	395	423	257	309	229	111	582	843
E. scheuz. 2	6	-	537	344	172	184	201	358	581	339
E. scheuz. 3	10	-	392	545	482	587	38	367	260	237
E. scheuz. 4	8	-	260	755	179	515	117	121	590	445
E. triste 1	10	-	0	3	1	1	1	0	3	11
E. triste 2	6	-	98	59	21	16	43	56	67	39
E. triste 3	10	-	0	0	0	0	0	0	0	0
E. triste 4	8	-	0	0	0	0	0	0	0	0
Arctostaphylos 1	-	-	-	-	-	-	-	-	1865	3035
Arctostaphylos 2	-	-	-	-	-	-	-	-	215	272
Arctostaphylos 3	-	-	-	-	-	-	-	-	387	375
Arctostaphylos 4	-	-	-	-	-	-	-	-	996	1216
Vaccinium 1	-	-	-	-	-	-	-	-	2521	9271

Table 3.4. Area size (m²) and pooled numbers of flower buds, flowers and senescent flowers of white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia, *moss campion* Silene acaulis, *arctic cotton-grass* Eriophorum scheuzerii *(corrected data for 1996) and 'dark cotton-grass'* Eriophorum triste *in flower plots 1995-2003. Numbers in brackets have been extrapolated from 1995 and 1996 data to make up for enlarged plots (see Meltofte and Rasch 1998).*

Plot	1996	1997	1998	1999	2000	2001	2002	2003
Salix 1	5	4	0	22	4	1	3	+
Salix 2	0	1	2	2	0	0	1	0
Salix 3	0	0	0	6	0	0	2	0
Salix 4	16	3	0	6	0	0	0	0

Table 3.5. Peak ratio (per cent) of female Salix *pods infested by fungi in* Salix *plots 1996-2003. + indicates that the peak ratio percentage is < 0.5.*

Species	Area	1998	1999	2000	2001	2002	2003
Arctostaphylos 1	1.5	148	240	30	99	33	122
Arctostaphylos 2	1.5	50	17	2	36	18	55
Arctostaphylos 3	1.5	28	91	4	100	32	21
Arctostaphylos 4	1.5	139	107	0	14	44	106
Vaccinium 1	4	240	532	9	0	1	14
Empetrum 1	4	27	1	17	3081	1034	4568

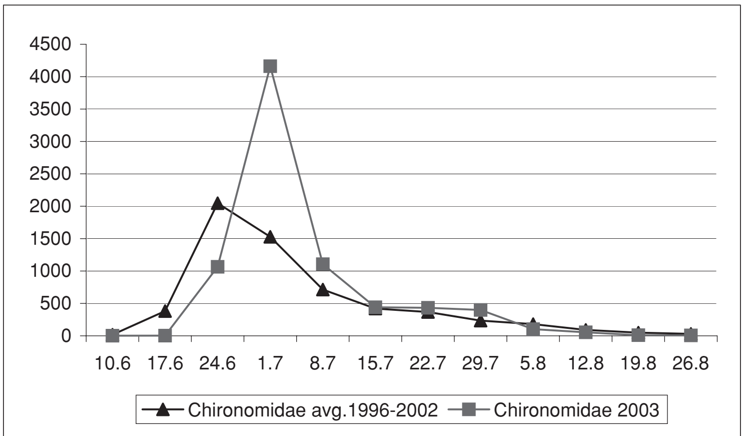
Table 3.6. Area size (m2) and number of berries recorded in alpine bearberry Arctostaphylos alpina, *arctic blueberry* Vaccinium uliginosum *and crowberry* Empetrum nigrum *plots 1998-2003.*

sorted material is kept in 70% alcohol at the Zoological Museum, University of Copenhagen and is available for further analysis.

Ice melt on the eastern pond in Gadekæret, where the window traps are situated, was late (Table 3.8 and section 2.2). Snowmelt in the pitfall trap plots was within the range from previous year, with Arthropod plots 2 and 7 in the late end, plot 3 and 5 close to mean and plot 4 in the early end.

The total number of arthropods collected this year (70,806) was almost at the same high level as last year (71,928). The total number of trapping days this year (3,269) was a little higher than last year (3,227). As the differences in trapping days between years are in the beginning of June, where the number of arthropods is low, it has only little impact on the total number of arthropods collected.

Figure 3.1. Number of Chironimid midges (Chironomidae) caught per week in window traps in 2003 compared with means for 1996-2002.



Window traps

The two window traps in Gadekæret were established on 3 June, when the pond was *c.* 97% ice covered, and they remained open until 26 August. Catches from the two traps were pooled for each week, and data are presented in Table 3.9 together with total catches from previous years.

The taxa composition of arthropods was almost similar to catches from previous years except for the parasitoids Megaspilidae, which where recorded for the first time in the window traps with two individuals. Other parasitoids, Ichneumonidae, showed the highest number recorded so far.

Chironimid midges (Chironomidae) was, as in previous years, the most numerous group recorded, and numbers were even higher than in 2002. Comparing Chironomidae number and peak time in 2003 and average number and peak time for 1996-2002 indicates that 2003 was close to average. A short distinct peak period occured in June, although the peak period this year was one week later than the average for the previous years (Figure 3.1).

Biting midges (Ceratopogonidae) were collected in very low numbers, and the noticeable peak in mid June 2002 was not present this year.

Pitfall traps

The first traps were opened on 3 June and the last on 17 June, giving a total of 3101 trapping days only exceeded by year 2000 with 3155 trapping days. Weekly totals are pooled for all five plots and presented in Table 3.10 with totals from 1998-2002 for comparison.

Springtails (Collembola) and mites (Acarina) were the most numerous groups collected in the pitfall traps, and both groups were present throughout the entire trapping period.

As a consequence of the warm weather in June and July, several arthropod groups were recorded in considerably higher numbers than in most previous years, and some groups were recorded at the highest number so far. This was apparent for aphids (Aphidoidea), butterflies and moths (Lepidoptera), sciarid flies (Sciaridae), tachinid flies (Tachinidae), bumble bees (*Bombus*) and the parasitoids (Ichneumonidae and Scelionidae).

Butterflies (*Colias hecla* and *Clossiana*) and

Plot	1999		2000		2001		2002		2003	
	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date
Cassiope 1	0.40	29.7	0.41	29.7	0.37	5.8	0.35	29.7	0.36	5.8
Cassiope 2	0.41	29.7	0.46	22.7	0.38	22.7	0.38	26.8	0.43	5.8
Cassiope 3	0.41	19.8	0.36	19.8	0.33	5.8	0.31	26.8	0.34	12.8
Cassiope 4	0.38	26.8	0.41	22.7	0.35	29.7	0.33	26.8	0.39	5.8
Mean	0.40		0.41		0.36		0.34		0.38	
Dryas 1	0.43	22.7	0.41	22.7	0.37	22.7	0.35	25.7	0.40	22.7
Dryas 2/Salix 7	0.39	19.8	0.42	22.7	0.39	29.7	0.43	5.8	0.42	5.8
Dryas 3	0.45	29.7	0.45	22.7	0.42	26.7	0.41	29.7	0.46	22.7
Dryas 4	0.34	19.8	0.32	22.7	0.33	22.7	0.28	29.7	0.29	22.7
Dryas 5	0.34	29.7	0.33	22.7	0.31	22.7	0.28	29.7	0.31	15.7
Dryas 6/Papaver 4	0.35	26.8	0.41	22.7	0.34	26.7	0.37	5.8	0.38	22.7
Mean	0.38		0.39		0.36		0.35		0.38	
Papaver 1	0.41	19.8	0.41	22.7	0.38	29.7	0.39	29.7	0.41	22.7
Papaver 2/Salix 5	0.44	19.8	0.45	22.7	0.41	29.7	0.40	5.8	0.42	29.7
Papaver 3	0.37	26.8	0.41	22.7	0.35	29.7	0.34	5.8	0.39	22.7
Mean	0.39		0.42		0.37		0.37		0.40	
Salix 1	0.57	29.7	0.59	22.7	0.54	8.7	0.54	22.7	0.60	15.7
Salix 2	0.52	29.7	0.52	22.7	0.49	29.7	0.51	22.7	0.50	22.7
Salix 3	0.41	29.7	0.44	22.7	0.39	29.7	0.38	29.7	0.38	22.7
Salix 4	0.46	29.7	0.47	22.7	0.43	2.8	0.45	29.7	0.47	15.7
Salix 6	-	-	-	-	-	-	-	-	0.39	31.7
Mean	0.46		0.48		0.44		0.45		0.46	
Saxifraga/Silene 1	0.28	29.7	0.34	7.8	0.27	8.7	0.19	22.7	0.27	15.7
Saxifraga/Silene 2	0.36	29.7	0.38	22.7	0.34	19.7	0.31	22.7	0.38	15.7
Saxifraga/Silene 3	0.23	29.7	0.26	22.7	0.27	15.7	0.20	29.7	0.24	22.7
Silene 4	0.32	26.8	0.36	22.7	0.27	29.7	0.26	5.8	0.28	29.7
Mean	0.30		0.34		0.29		0.24		0.29	
Eriophorum 1	0.57	5.8	0.60	14.7	0.60	29.7	0.57	29.7	0.61	15.7
Eriophorum 2	0.58	29.7	0.58	22.7	0.53	26.7	0.50	29.7	0.45	15.7
Eriophorum 3	0.54	19.8	0.56	22.7	0.47	29.7	0.47	29.7	0.48	22.7
Eriophorum 4	0.73	5.8	0.72	22.7	0.68	29.7	0.64	5.8	0.67	22.7
Mean	0.61		0.62		0.57		0.54		0.55	
Mean of all	0.43		0.44		0.40		0.39		0.41	

Table 3.7. Peak NDVI recorded in 27 flower plots 1999-2003 together with date of maximum record using a hand held Skye 110 instrument with a 660-730 nm sensor. NDVI values presented are transformed averages of eight (four in very small plots) hand held RVI measurements in each plot. Note that the greening measured accounts for the entire plant community, in which the taxon denoted may only make up a minor part. Mean of e.g. Salix plots also involve Salix plots 5 and 7.

moths (Noctuidae) were particularly abundant this year and were recorded in the highest number so far. The main lepidopteran flight activity was from the middle of July until the beginning of August (see also section below on visual observations).

The number of chironomid flies (Chironomidae) was a little smaller than last year, but still the second most numerous dipteran group recorded. Although the main peak was in the last week of June, there were some differences between the pitfall trap stations (Figure 3.2). Station 2 captures far the largest proportion of Chironomidae among the pitfall trap stations, and the peak time was identical to the peak time at the window traps.

Houseflies (Muscidae) was the most numerous diptera group present in the pitfall traps, and the number exceeded last year's record. The data from this year shows two periods with high flight activity. The first peak was in the first week of July and the second peak two weeks later. The two peaks are more pronounced than the mean flight activity for 1996-2002 (Figure 3.3).

Sawflies, bumble bees and parasitoids (Hymenoptera) were collected in the highest numbers so far (1474), almost twice as many as mean numbers of previous years. Particularly the parsitoids Ichneumonidae, Bracoinidae, Chalcidoidea and Scelionidae were quite numerous. It is worth to notice that the egg parasites Scelionidae were

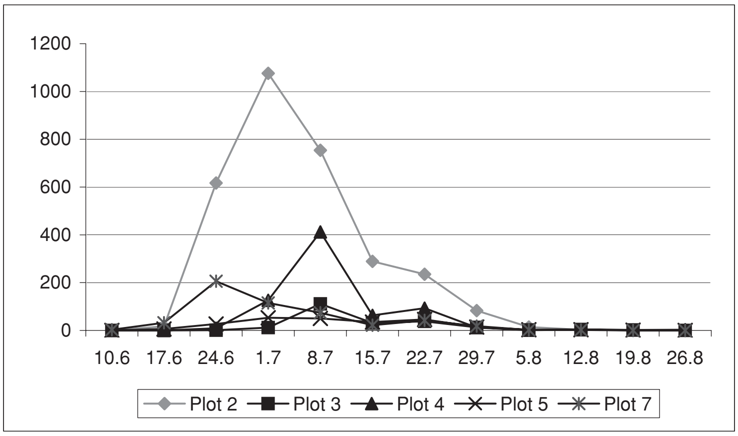


Figure 3.2. Number of chironimid midges (Chironomidae) caught per week in five pitfall trap stations in 2003.

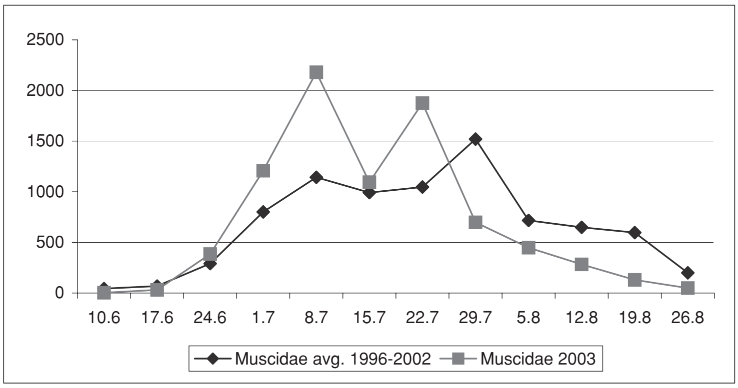


Figure 3.3. Number of houseflies (Muscidae) caught per week in pitfall traps in 2003 compared with means for 1996-2002.

collected in numbers three times higher than the previous highest record in 1999. The number of larvae was relatively high as well, and sawfly larvae (Tenthridinidae) were represented by seven individuals, but no adults were collected from any of the traps. It is remarkable that adult sawflies have never been collected from pitfall traps or in window traps.

Station no.	1996	1997	1998	1999	2000	2001	2002	2003
Art. 1	3.6	Dry	6.6	16,6	1.6	6,6	3.6	12.6
Art. 2	<3.6*	28.5	29.5	8.6	<4.6*	<31.5*	<31.5*	1.6
Art. 3	14.6	19.6	18.6	27.6	9.6	19.6	14.6	20.6
Art. 4	14.6	22.6	26.6	2.7	7.6	21.6	20.6	11.6
Art. 5	4.6	<29.5*	1.6	12.6	<4.6*	8.6	3.6	5.6
Art. 7	-	-	-	<3.6	<4.6*	<30.5	<31.5*	2.6

* 0% snow

Table 3.8. Date of 50% snow-cover (ice cover on pond at Station 1) in the arthropod plots 1996-2003.

Insect predation on *Dryas flowers* and *Salix arctica*

One larva of 'black moth' *Sympistis zetterstedtii* was found in Dryas 5 on 1 July, and depredation was recorded in most plots (Table 3.11).

One woolly-bear *Gynaephora groenlandica* caterpillar was recorded inside the Salix 3 plot on 17 June, and as many as 27 larvae were recorded by Hans Meltofte during bird census in June and July (Table 3.12). This is the highest number recorded so far. The first one was seen at our arrival on 3 June, and by early July, almost all had protected themselves by cocoons.

Sawfly Tenthredinidae larvae were found in four ripe female willow pods in the Salix 3 plot (Table 3.13).

Bumblebees and butterflies

The first bumblebee *Bombus polaris/hyperboreus* was recorded on 5 June. During bird census work in June and July, a total of 111 individuals were recorded by Hans Meltofte (for effort, see Table 3.15). This is the highest number recorded so far (Table 3.14), probably due to the outstandingly warm and dry weather in most of June and July. During the line transects in July, 17 bumblebees were seen in Store Sødal and two between Daneborg and Zackenberg, which is the same as in 2002.

Also fritillary *Clossiana* sp. and arctic clouded yellow *Colias hecla* butterflies were recorded systematically during bird census work in June and July. The first fritillary was seen on 16 June and the first arctic clouded yellow on 24 June. This latter date is the earliest so far. Total numbers seen were 35 fritillary in June and 320 in July. Six arctic clouded yellows were seen in June and 243 in July. These high numbers are very much the same as in 2002, with the exception of the even higher number of arctic clouded yellows in July 2003. Like in 2002, this reflects the warm and dry weather in most of June and July, when up to 63 fritillary and 51 arctic clouded yellow butterflies were recorded in one day. Very high numbers of butterflies were also taken in the pitfall traps (see above).

Date	10.6	17.6	24.6	1.7	8.7	15.7	22.7	29.7	5.8	12.8	19.8	26.8	2003	2002	2001	2000	1999	1998	1997	1996
No. of trap days	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**168**	**168**	**168**	**166**	**153**	**174**	**184**	**182**
COLLEMBOLA		1	1	5	2	8		1	1	4	4	4	31	191	119	102	61	5	15	65
COLEOPTERA													0							
Latridius minutus													0	0	0	0	2	0	0	0
HEMIPTERA													0							
Nysius groenlandicus													0	1	0	0	0	0	0	4
Aphidoidea												1	1	0	2	0	0	0	0	0
Coccoidea													0	0	0	3	0	0	0	14
THYSANOPTERA													0	3	1	0	0	0	0	8
LEPIDOPTERA																				
Colias hecla							1		1				2	6	0	2	0	0	0	1
Clossiana sp.							1		3				4	1	1	2	1	1	1	6
Geometridae													0	2	3	0	0	0	1	3
Noctuidae						1							1	0	0	0	0	0	2	2
DIPTERA																				
Nematocera larvae													0	2	0	0	1	0	0	0
Nematocera undet.													0	0	1418	0	0	0	0	0
Tipulidae							1						1	0	0	0	1	0	0	0
Trichoceridae													0	0	0	0	0	1	1	0
Culicidae				7	55	11	19	2	2				96	232	209	111	322	138	142	98
Chironomidae	2	13	1065	4162	1106	440	432	399	103	54	10	6	7792	6378	3876	8522	5787	3743	7725	6477
Ceratopogonidae					6	31	10	7	7	4	1		66	1598	168	*	1799	*	*	*
Mycetophiliidae				1		1							2	6	23	22	16	624	240	64
Sciaridae			4	3	3		1		1				12	56	33	2	171	*	*	*
Cecidomyiidae													0	3	4	32	6	0	0	1
Empididae						4	4						8	1	8	10	9	9	1	77
Phoridae													0	1	1	2	3	0	0	0
Syrphidae				1	2				1	2			6	10	4	5	1	8	16	4
Heleomyzidae													0	1	2	0	1	0	0	0
Agromyzidae					1							1	2	3	0	0	0	0	4	0
Tachinidae					1	1	1		1	2		1	7	0	2	6	1	0	0	0
Calliphoridae	1												1	1	1	4	5	7	6	2
Scatophagidae						1						2	3	7	0	2	10	0	30	11
Anthomyiidae	3	3	1	1						2			10	8	2	*	3	26	11	*
Muscidae	1		29	84	268	114	161	89	46	44	19	11	866	554	1312	1455	754	745	809	1355
HYMENOPTERA																				
Bombus sp.							1			2			3	1	0	0	1	2	6	5
Ichneumonidae				1	7	11	22	15	4	4	4	2	70	24	34	48	24	18	44	43
Braconidae													0	0	0	0	0	1	1	0
Chalcidoidea						1							1	2	14	0	0	0	2	0
Ceraphronoidea						1		1					2	0	0	0	0	0	0	0
ARANEA																				
Lycosidae						1							1	1	0	2	0	0	1	0
Linyphiidae						1		1		1	3	2	8	8	15	10	6	1	1	8
ACARINA		1	3	9	1	1	5	5	15	12	1	1	54	347	358	246	191	826	189	299
Total	7	18	1103	4274	1452	628	659	520	185	131	42	31	9050	9448	7610	10588	9177	6155	9248	8547

Table 3.9. Weekly totals of arthropods etc. caught at the window trap station in 2003. The station holds two window traps situated perpendicular to each other. Each window measures 20 x 20 cm. Values from each date represents catches from the previous week. Totals from 1996-2002 are given for comparison. Asterisks mark groups that were not separated from closely related groups.

Date	10.6	17.6	24.6	1.7	8.7	15.7	22.7	29.7	5.8	12.8	19.8	26.8	2003	2002	2001	2000	1999	1998
No. of active stations	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
No. of trap days	105	196	280	280	280	280	280	280	280	280	280	280	3101	3059	2954	3155	2706	2702
COLLEMBOLA	47	474	996	1380	3357	2344	1027	986	682	4639	881	697	17510	20312	17970	21726	23443	8957
HETEROPTERA													0					
Nysius groenlandicus								1		1	1		3	0	2	0	1	0
Aphidoidea		3	11	56	606	269	371	116	90	60	27	15	1624	157	359	3	11	185
Coccoidea									14	16	6	6	42	634	9	781	431	3
THYSANOPTERA													0	5	0	0	2	0
LEPIDOPTERA																		
Lepidoptera larvae			4	7	7		2	5	2	3	4	3	37	63	16	18	21	106
Tortricidae							1						1	0	1	0	0	0
Colias hecla					11	6	89	37	12	1			156	29	0	77	42	12
Clossiana sp.				1	14	7	160	151	100	35			468	381	49	329	82	56
Lycaenidae													0	0	0	4	1	0
Plebeius franklinii													0	7	19	0	0	1
Geometridae													0	6				
Noctuidae				2	10	1	33	24	27	12	1		110	1	15	4	6	2
DIPTERA																		
Nematocera larvae	10	9	2	1	1	4				2			29	46	15	279	105	58
Tipulidae larvae						1		1				1	3	3	3	4	1	0
Tipulidae					4	1	1	1					7	4	14	2	4	1
Trichoceridae										1			1	1	7	0	3	0
Culicidae			2	4	5	3	1	5	3				23	86	34	61	83	22
Chironomidae	3	55	860	1368	1401	440	454	140	22	15	5	5	4768	5982	1958	3666	8542	2402
Ceratopogonidae			9	16	37	12	10	12	6	2	3		107	102	7	0	68	*
Mycetophiliidae		10	3	3	9	14	21	1	4	4	1		70	48	181	820	205	1764
Sciaridae		7	125	212	362	152	175	46	16	4	1	1	1101	762	573	4	796	*
Cecidomyiidae				4	1	2	1						8	6	8	24	0	1
Brachycera larvae	1							1		1			3	0	0	4	3	0
Empididae			1		3		1	1	2				8	24	28	14	21	10
Cyclorrhapha larvae	2	1	2	2	2	1	1	3	3	1	3	2	23	22	0	7	7	19
Phoridae		5		7	105	88	242	97	84	17	11	9	665	489	445	1316	435	344
Syrphidae	1		4	5		6	3	5	6	4	1		35	30	18	43	50	28
Heleomyzidae												1	1	5	6	1	7	0
Agromyzidae	1	1			1	1				1	1	4	10	6	4	2	0	0
Tachinidae					1	3	9	9	16	9	9	4	60	23	29	37	37	0
Calliphoridae						1		1	5	3	4	3	17	44	5	218	26	49
Scatophagidae						1	6	4	7	9	7	8	42	24	0	1	41	0
Fannidae													0	0	0	0	0	0
Anthomyiidae	4	7	6	6	5		2	1	3	42	18	14	108	238	57	*	88	416
Muscidae	3	31	385	1208	2180	1094	1876	698	448	283	130	49	8385	7499	6766	12805	10005	5463
SIPHONAPTERA													0	0	0	0	3	0
HYMENOPTERA																		
Hymenoptera larvae							2	4	2				8	0	0	4	0	2
Bombus sp.				1				4	3	4	3		15	7	3	10	2	6
Ichneumonidae		2	1	23	208	186	250	109	78	45	35	37	974	436	442	710	386	297
Braconidae		1	7	3	13	5	10	3	1	2	4	3	52	11	11	15	10	105
Chalcidoidea			2	2	10	6	20	21	24	17	8	10	120	190	106	21	9	2
Scelionidae					2		5	24	106	101	42	30	310	5	3	0	101	0
Ceraphronoidea							2	1					3	8	3	15	5	0
Cynipoidae													0	0	1	0	0	0
ARANEA																		
Thomisidae		25	38	14	20	7	21	8	9	12	5	5	164	219	177	134	144	89
Lycosidae	3	94	468	491	413	101	331	279	652	412	103	91	3438	1760	2618	3254	2118	2123
Lycosidae egg sac			1	7	25	3	29	7	2	3	1	7	85	12	85	101	160	160
Dictynidae		1	9	1	2		3					2	18	107	0	0	79	0
Linyphiidae	92	323	312	107	111	61	174	249	283	225	237	352	2526	1438	1833	3523	2243	1108
ACARINA	101	361	530	798	1876	1682	6354	1797	2464	1237	942	460	18602	21282	9929	15256	8263	6304
OSTRACODA		12											12	9	0	46	84	0
NEMATODA	1	1								1	1		4	0	0	3	0	0
ENCHYTRAEIDAE													0	1				
Unidentified													0	0	0	2	0	0
Total	269	1423	3778	5729	10802	6502	11687	4852	5176	7224	2495	1819	61756	62523	43811	65344	58174	3009

Table 3.10. Weekly totals of arthropods etc. caught at the five pitfall trap stations in 2003. Each station holds eight yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous week. Totals from 1997-2002 are given for comparison. Asterisks mark groups that were not separated from closely related groups.

Plot	1996	1997	1998	1999	2000	2001	2002	2003
Dryas 1	2	6	3	0	0	0	15	2
Dryas 2	0	5	0	0	0	0	1	0
Dryas 3	11	18	3	0	0	0	7	1
Dryas 4	17	1	7	0	0	0	11	5
Dryas 5	2	8	2	0	0	0	9	2
Dryas 6	0	0	0	0	0	0	0	0
Dryas 7	-	-	0	26	0	0	2	3
Dryas 8	-	-	0	27	0	0	0	11

Table 3.11. Peak ratio (per cent) of mountain avens flowers depredated by larvae of 'black moth' Sympistis zetterstedtii *in mountain avens plots in 1996-2003.*

Month	1996	1997	1998	1999	2000	2001	2002	2003
June	1	2	7	7	10	2	4	25
July	0	1	4	17	2	2	3	2
Total	1	3	11	24	12	4	7	27

Table 3.12. Number of woolly-bear Gynaephora groenlandica *caterpillars recorded by one observer in study area 1A (the bird monitoring area) in June and July 1996-2003 (see Table 3.15 for effort).*

Plot	1996	1997	1998	1999	2000	2001	2002	2003
Salix 1	+	0	0	43	2	0	0	0
Salix 2	3	0	0	6	0	0	0	0
Salix 3	9	0	0	3	5	0	0	2
Salix 4	0	0	0	1	7	0	0	0

Table 3.13. Peak ratio (per cent) of female arctic willow pods infested by sawfly larvae in 1996-2003. + indicates that numbers were not quantified.

3.3 Birds

Hans Meltofte

Bird observations were recorded by myself during 3 June – 5 August and by Thomas B. Berg during 26 June – 2 September. Valuable observations were provided by other researchers and staff during the entire season.

During June, the main effort was to census the breeding birds within the 19 km^2 census area in Zackenbergdalen, while in July emphasis was on breeding phenology, *i.e.* finding nests and young and rechecking these. During late July and all of August, waders and other waterbirds were counted every third day in the recent and the old delta of Zackenbergelven.

Besides the BioBasis personnel, at team of five Dutch ornithologists lead by Theunis Piersma worked intensively in the bird census area (see section 5.8), and they supplied a large amount of nest and pulli records.

For scientific names in this section, see section on Other observations.

Breeding populations

New field maps of the bird census area in Zackenbergdalen were produced this year, and the area of the different sections was recalculated, giving a new area of 19.3 km^2 (see Table 3.16). At the same time, the UTM positions of nests, broods and territories were adjusted in the bird databases by moving the 1995-2001 positions 70 m SE. This was done by subtracting 50 m from the Northings and adding 50 m to the Eastings. The inaccuracy was somewhat higher up the slopes of Aucellabjerg, but this has not been corrected for.

The census area was covered on almost daily trips between mid June and late July (Table 3.15). The total effort in both June

Month	1999	2000	2001	2002	2003
June	-	59	12	48	95
July	35	34	15	31	16
Total	-	93	27	79	111

Table 3.14. Number of bumblebees Bombus polaris/hyperboreus *recorded by one observer (Hans Meltofte) in study area 1A (the bird monitoring area) in June and July 1999-2003.*

	West of river	East of river	Total
June	6; 24	14; 59	20; 83
July	11; 39	15; 55	26; 94
Total	17; 63	29; 114	46; 177

Table 3.15. Number of trips and hours (trips; hours) allocated to bird censusing and breeding phenology sampling west and east of Zackenbergelven during June and July, respectively.

	West of river <50 m 3.47 km²	East of river <50 m 7.77 km²	East of river 50-150 m 3.33 km²	East of river 150-300 m 2.51 km²	East of river 300-600 m 2.24 km²
Red-throated diver	0	2	0	0	0
Pink-footed goose	0	0	0	0	0
Common eider	0	0	0	0	0
King eider	0	1	0	0	0
Long-tailed duck	0	7-9	0	0	0
Rock ptarmigan	0	0	0	0	0
Common ringed plover	4	4	2	11	7
Red knot	2	11	4	6-7	1
Sanderling	13-15	26-30	4-5	15	7
Dunlin	25-26	66-73	10-11	1	2
Ruddy turnstone	2-3	17	14	0	0
Red-necked phalarope	0	1-2	0	0	0
Long-tailed skua	3-4	12-15	10	0	0
Arctic redpoll	1	0	0	0	0
Snow bunting	25	9-10	19-20	4	2

Table 3.16. Estimated number of pairs/territories in five sectors of the 19.3 km² census area in Zackenbergdalen, 2003.

and July was similar to previous years. The initial complete census of waders took place between 12 and 19 June and took 37 hours to complete. During the census, most waders had eggs (see section below), and few individuals appeared to be unsettled. The weather was fine or at least acceptable during the census days.

Based on records made during the initial census supplemented by records during the rest of the season (see Meltofte and Berg 2003), population estimates for five sections of the census area are presented in Table 3.16, and in Table 3.17 they are compared to previous years. Most populations were within the range estimated for earlier years, but ringed plovers were lower than recorded before, and turnstones remained as low as in 2002. The continued increase in Dunlin numbers came to a halt.

I feel confident that the low numbers of turnstones are real, and they may be the continued result of three consecutive problematic breeding seasons at Zackenberg 1999-2001 (see Caning and Rasch 2000, 2001, 2003). The somewhat reduced number of dunlins should not be taken too literally, since recording of this species is somewhat problematic. The same applies to ringed plover, but still the much-reduced number is remarkable.

The somewhat high number of sanderlings this year was the result of an intensive effort on nest-finding by Theunis

Table 3.17. Census results from the 19.3 km² census area in Zackenbergdalen 1996-2003.

	1996	1997	1998	1999	2000	2001	2002	2003
Red-throated diver	1-2	2	3	2-3	2-3	2	3	2
Pink-footed goose	0	1	0-1	2	1	1	1	0
Common eider	0	0	0	0	1	1	1	0
King eider	2-3	2	1	2-3	2-4	3-4	4-6	1
Long-tailed duck	5-8	4-6	6-8	7-8	5-8	5-7	6-7	7-9
Rock ptarmigan	3	11-15	4-6	7-8	1-3	2-4	3	0-1
Common ringed plover	54-56	40-48	38-45	51-65	41-43	51-54	37-41	28
European golden plover	0	0	0	0	0	1	0	0
Red knot	33-43	35-44	27-32	25-33	24-27	27-30	24-27	24-25
Sanderling	50-63	55-70	62-70	60-67	59-67	58-70	49-55	65-72
Dunlin	69-82	75-91	75-94	81-95	98-103	104-110	120-132	104-113
Ruddy turnstone	42-52	49-58	56-63	43-49	48-50	45-51	31-37	33-34
Red-necked phalarope	0-1	0-2	1-2	1-2	1-2	1-2	1-2	1-2
Red phalarope	0	0	0-1	0	0	1	0	0
Long-tailed skua	25-29	22-25	21-24	19-24	21-28	22-25	23-26	25-29
Northern wheatear	0	0	1	0	0	0	0	0
Arctic redpoll	0	0	0	0	0	0	0	1
Snow bunting	45-55	45-56	41-46	52-64	42-47	48-58	58-61	59-61

Piersma and his group within a 4 km² study plot on the slopes of Aucellabjerg, which revealed 15 nests and a further seven broods in an area, where my rapid assessment had resulted in an estimate of 13-17 pairs (Piersma *et al.* in prep.). Since some of the sanderlings produce double-broods, these results are not too far apart, especially considering the fact that most of the area in question – the western and upper parts of the slopes – are the last to be covered during the census, and therefore are most prone to underestimation of the sanderlings (Meltofte 2001).

For the first time neither territorial male ptarmigans nor pairs were recorded inside the census area, but on 29 July a female with 11 chicks appeared at 250 m a.s.l. on the slopes of Aucellabjerg. A brood of three large chicks was also recorded at 180 m a.s.l. on mountain Zackenberg (see also Other observations below).

Reproductive phenology and success in waders

The snow cover was extensive in early June, but it was relatively thin and disappeared fast (see section 2.2). Still, on 10 June only 17% of the census area below 300 m a.s.l. was snow-free (Table 3.19). Median 1st egg dates were relatively early, with sanderlings earlier than recorded before, ruddy turnstones among the earliest and dunlins close to average (Tables 4.18 and 4.19). The very earliest clutches in dunlin and ruddy turnstone were almost as early as the exceptionally early clutches of 2002, when temperatures in late May and early June were unprecedented high and arthropods plentiful (Rasch and Caning 2003).

I see no obvious explanation for the very early initial clutches in dunlin and ruddy turnstone or for the early median egg-laying date in sanderling. This year, two thirds of the sanderlings were found above 100 m a.s.l. on the slopes of Aucellabjerg, where the median date was 12 June, while it was 15 June below 100 m a.s.l. (where most data were obtained in previous years). However, the difference is not statistically significant. The early median in ruddy turnstone may partly be a result of the reduced population (see above), since the remaining pairs to a high extent were concentrated in Oksebakkerne, an area snow free early in the season. The late clearing lowland was almost devoid of turnstones.

The weather was warm and dry during most of the incubation period, with a mean temperature in July higher than recorded before at Zackenberg (see section 2.1). Hence, no periods of inclement weather hampered breeding success this year. Considering the record high number of sanderling nests found (19) it is noteworthy that not a single nest with less than four eggs was found (Table 3.20). The same applies to dunlin, whereas only one turnstone nest held three eggs and one had two eggs out of the 13 nests found.

Nest depredation was higher than found before (Table 3.21), but this was most likely the result of the intensive work at most nests this year. Hence, nests were visited with one or a few day's intervals, and traps were set over the nests several times. By far, most predation must have been by foxes, of which an estimated total of at least five individuals were hunting inside the bird census area during June and July (see section 5.7 on special efforts on foxes this year). Three dens (two inside the area and and one 2 km to the eas) held pups. In total, seven fox encounters were

	Median date	Range	N
Common ringed plover	11 June	8-13 June	3
Red knot	12 June	4-28 June	9
Sanderling	13 June	5-28 June	36
Dunlin	12 June	2 June - 4 July	23
Ruddy turnstone	8 June	2-22 June	17

Table 3.18. Median first egg dates for waders at Zackenberg in 2003 as estimated from incomplete clutches, egg floating, hatching dates and weights of pulli.

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Snow cover on 10 June	84	82	76	80	91	53	84	79	83
Sanderling		(16 June)	18 June	18 June	23.5 June	16 June	22.5 June	17 June	13 June
Dunlin	(18 June)	11.5 June	13 June	16.5 June	22 June	11.5 June	25 June	8 June	12 June
Ruddy turnstone	(12 June)	18.5 June	13 June	12.5 June	24 June	11 June	23 June	9 June	8 June

Table 3.19. Snow cover on 10 June together with median first egg dates for waders at Zackenberg 1995-2003. Data based on less than 10 nests/-broods are in brackets, less than five are omitted. The snow cover is pooled (weighted means) from sections 1, 2, 3 and 4 (see section 2.2), from where the vast majority of the egg laying phenology data originate.

Table 3.20. Mean clutch sizes in waders at Zackenberg 1995-2003. Samples of less than five clutches are given in brackets.

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Common ringed plover	(4.00)	(4.00)	(3.50)	(4.00)	(3.50)	(4.00)	(3.5)	(4.00)	(4.00)
Red knot				(4.00)	(4.00)		(4.00)		(4.00)
Sanderling	(4.00)	4.00	3.86	4.00	3.67	4.00	3.43	3.83	4.00
Dunlin		(4.00)	(3.75)	3.90	3.70	3.93	3.63	(4.00)	4.00
Ruddy turnstone		3.71	3.79	3.81	3.58	3.75	3.75	4.00	3.77

Table 3.21. Predation rates on wader nests at Zackenberg 1996-2003 expressed as minimum and maximum of nests depredated (with eggs) throughout the nesting period. Partially depredated nests are given as successful, if at least one young hatched, and so are nests with starred or pipped eggs that were found empty and without indications of predation later on. Nest failures for other reasons are omitted. Samples of less than five nests are given in brackets. Also given are total number of fox encounters in the bird census area during June-July and the number of fox dens holding pups. Foxes seen on the research station are omitted.

	1996	1997	1998	1999	2000	2001	2002	2003
Common ringed plover	(100)	(0-25)	(0)	(25)	(0-25)	(25-50)	(0)	(0)
Red knot			(0-100)	(50)		(100)		(100)
Sanderling	17	0-40	0-11	21-29	17-33	57	50	42
Dunlin	(0)	(0)	11-33	0-33	13	13	(25)	25
Ruddy turnstone	0-29	0-8	27-47	18-55	33-38	20	13-38	50-58
Red-necked phalarope				(100)				
All species pooled	13-27	0-17	14-34	20-39	22-28	30-33	26-37	40-43
N	15	24	35	41	46	30	19	47
Fox encounters	14	5	7	13	11	14	21	11
Fox dens with pups	2	0	1	0	2	2	1?	2

recorded during bird censusing in June and four in July (Table 3.21).

Two dunlin nests were only partially depredated (probably by skuas, since one and two cold eggs, respectively, were left behind in the disturbed nest cups). A further two eggs in a dunlin nest and one egg in a turnstone nest did not hatch, while one egg in a turnstone nest was deserted when almost hatched (three young hatched successfully).

Numbers of juvenile waders recorded on the intertidal delta flats at the coast of Zackenbergdalen were within the range from previous years (Table 3.22). The accumulated grand total of 803 juveniles was in the lower end of the range, but still 2003 must have been a favourable breeding season for waders in central Northeast Greenland (see also Waders under Other observations below).

Reproductive phenology and success in long-tailed skuas

Only two lemmings were seen inside the bird census area during the whole summer, and the number of winter nests within the 2 km^2 lemming census area was the lowest recorded so far (Table 3.23 and section 3.4). Still, at least seven skua pairs out of an estimated population of 25-29 pairs (Table 3.17) produced clutches, but only of one egg each. Most surprisingly, only one nest was depredated, and five young hatched (one nest failed due to our activities). Of these, three young were predated and two fledged (Table 3.23).

The egg laying phenology was in the late end of previous years (Table 3.23). The first egg was laid on 13 June, and the last original clutches were initiated on 16 June, while one supposed replacement clutch was initiated on 26 June.

Breeding barnacle geese

Only nine pairs of barnacle geese brought goslings to the coast of Zackenbergdalen this year. The first two families appeared at Lomsø on 29 June, close to previous years. On 5 July, six pairs were present in Lomsø and in Kystkærene, besides 118 immatures and seven adults without goslings (see Other observations). At least one other pair brought goslings to the base of the peninsula to the east, since at least two goslings were taken by foxes here. Two families were found in Langemandssø on 26 July. Mean brood size of successful families was the lowest recorded so far (Table 3.24).

On the other hand, more barnacle goose families were recorded on the line transect through Store Sødal during 17-19 July than in previous years *i.e.* a total of 14 families with an average of 2.6 goslings. Some 'lumping' of broods may have been involved, however. (See also section below.)

The mean brood size and the juvenile percentage on the wintering grounds in

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Common ringed plover	96	126	249	42	44	142	320	140	170
Sanderling	304	726	149	333	445	366	540	156	242
Dunlin	325	360	323	232	509	273	326	554	309
Ruddy turnstone	80	108	82	109	23	73	162	183	75
Waders total	810	1342	803	722	1021	854	1351	1040	803

Table 3.22. Cumulative number of juvenile waders recorded at low tide in the old and the present deltas of Zackenbergelven during counts every third day in the period 20 July - 31 August, 1995-2003. In case of missing counts, data have been interpolated.

	1996	1997	1998	1999	2000	2001	2002	2003
Median 1st egg date	-	7.6	12.6	17.6	18.6	15.6	9.6	15.6
No. of clutches found	8	17	23	7	5	21	14	7
No. of young hatched	1	25	16	1	2	18	14	5
No. of young fledged	0	5	6	1	0	5	4	2
Lemming winter nests	161	366	721	331	192	326	282	96

Table 3.23. Egg laying phenology together with breeding effort and success in long-tailed skuas at Zackenberg 1996-2003. Median egg laying date is the date, when half the original clutches were laid, thus excluding clutches estimated to have been replacements. Number of clutches found includes replacement clutches, while number of young fledged is the estimated maximum breeding output of the season. Also given are number of lemming winter nests within our 2.05 km^2 lemming monitoring area (see section 3.4).

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Primo July		(3.0)	3.1	(2.9)	1.9	(3.2)	(1.8)	2.4	(1.8)
Medio July		(2.3)	2.7	2.3	1.8	(3.1)	(1.7)	2.4	(1.2)
Ultimo July	(2.0)	(3.0)	2.6	2.2	1.7	3.1		2.3	(1.1)
Primo August	(2.3)	(2.3)	2.4		1.8		(2.0)	2.2	(1.2)
No. of broods	>7	6-7	19-21	>18	29	11	4	32	8
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23	1.59
Per cent juv.	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5	6.4

Table 3.24. Average brood sizes of barnacle geese in Zackenbergdalen during July and early August, 1995-2003, together with the total number of broods brought to the valley. Samples of less than 10 broods are given in brackets. Data from autumn on the Isle of Islay in Scotland are given for comparison, including per cent juveniles in the population (Malcolm Ogilvie in litt.).

Scotland confirm the poor breeding season for Greenland barnacle geese (Table 3.24). In fact, 2003 had the lowest juvenile percentage after 1997 and the lowest average brood size during the last nine years of comparison (Malcolm Ogilvie *in litt.*). The only apparent reason for this on the Northeast Greenland breeding grounds was that the snow cover was very extensive early in the season (late May) in most areas.

Line transects

The results of the line transect counts in mid July through Store Sødal and between Daneborg and Zackenberg are generally within the range of records from previous years (Tables 4.25 and 4.26). Numbers of moulting immature pink-footed geese in Store Sødal were again very low, but barnacle geese were back to normal and more broods than before were found this year (see further in section above and on Other observations).

Sandøen

On 2 June, when we passed Daneborg by plane, open water areas were present between Sandøen and Kap Berghaus and to the southwest of the island (see section 2.2). On 9 June, most ice around Sandøen had disappeared, but an ice-bridge to the island remained. This ice-bridge did not disappear until between 20 and 24 June (observations by Sirius Dogsledge Patrol).

The number of common eiders, arctic terns and Sabine's gull nesting on the island seemed to be similar to previous years (Erik Born *in litt.*). On 3 August, 100-200 Sabine's gulls were feeding on the fjord north of the island.

Furthermore, two pairs of lesser black-

Table 3.25. Birds recorded (adults; young) during line transect surveys through Store Sødal and from Daneborg to Zackenberg (see map in Meltofte and Thing 1997) in mid July 2003.

	Store Sødal 17-19.7	Daneborg 16.7
Red-throated diver	6; 1	
Pink-footed goose	38	
Barnacle goose	191; 36	10
Common eider		15; 7
Long-tailed duck	1	
Common ringed plover	51	3
Red knot	1	
Sanderling	6	3
Dunlin	57	3
Ruddy turnstone	6	2
Long-tailed skua	1	5
Glaucous gull	8	4
Arctic tern	2	
Northern weathear		3
Common raven		9
Snow bunting	107; 41	9; 6

backed gull were present on the island during visits by ornithologists 10-20 August, and a nest with four eggs was found and photographed (Magnus Elander *in litt.*). This is the first record of breeding of the species in East Greenland (Boertmann 1994). Lesser black-backed gulls have been recorded in increasing numbers in Northeast Greenland in recent decades, and in recent years the species has been recorded several times in Young Sund and at Zackenberg (see previous issues of Zackenberg Ecological Research Operations' annual reports).

Other observations

This section deals with bird observations not reported in the previous sections. When nothing else is stated, observations refer to the census area in Zackenbergdalen.

Red-throated diver *Gavia stellata*

Six pairs nested in Zackenbergdalen this year, and most likely three of them fledged one chick each. The first pair circled over the research station on 4 June, but calls were possibly heard earlier. The first bird was sitting on the water in the delta of Zackenbergelven on 6 June, and on the next day, a pair landed near the breeding pond in Sydkærene. On 14 June, one of the birds was incubating, but the nest had been depredated by 18 June, when the pair visited the eastern pond in Gadekæret. Here they started to incubate on 29 June, but on 24 July, only a few days before hatch, this nest was also depredated.

On 12 June, a pair was present in Kystkærene, and on 20 June they were building a nest on the north shore of Lomsø. Incubation started on 22 June, but less than two days later the nest had been depredated, and one of the birds was sitting on a new nest on the south shore. Here the pairs were incubating until 30 June, so it is possible that the second egg of the initial clutch was laid here, though it may also have been predated. Again on 10 July, one of the birds was sitting on a mud-nest in the lake, and on 11 August, two very small chicks were seen on the lake. Between 24 and 30 August, only one chick remained.

On 21 June, a pair was seen on Vesterport Sø, where one was incubating on 23 June. However, already by 26 June, the nest had been depredated. The pair renested in Hestehalesø, where they had one egg on 3 July and were seen incubating until 17 July. On 26 July, the nest was empty, and the birds were gone.

On the shore of Østersøen, north of the peninsula, a bird was seen incubating between 3 and 20 July, and on 29 July the pair had two a-few-days-old chicks on the lake. Both chicks were still present on 13 August, but on the 27 August only one was seen.

On 17 July, a pair had one chick on Lindemanssø, and on 15 August one of the adults was present together with the large young.

On the small lake, Trap in Morænebakkerne, a pair was found with two chicks on 7 August, and on 15 and 18 August, one adult with one chick was present.

Furthermore, pairs and single individuals were seen on Ryledammene and Tørvedammen in July and August.

In June, up to two pairs were feeding off the delta of Zackenbergelven, and in July and August up to six individuals were found on the fjord off the valley. Three pairs were also seen feeding in Zackenbergelven above the outlet of Lindemanselven.

Pink-footed goose *Anser brachyrhynchus*

The first pink-footed geese were seen on 6 June, when at least seven apparently immatures were present. A few were seen almost daily until the moult migration of

	1997	1998	1999	2000	2001	2002	2003
Red-throated diver	3	2		2	3	5; 1	6; 1
Great northern diver				2; 1			
Pink-footed goose	263	123	27	56	85	37	38
Barnacle goose	182	250; 23	227; 23	261; 14-16	260; 1	138	201; 36
Goose sp.	25						
Common eider	390	119; 5	55; 6	10	11; 6	7	15; 7
Long-tailed duck	13		2				1
Rock ptarmigan	2	1				1; 2	
Common ringed plover	71	70	(78)	(105; 4)	63; 1	54	54
Red knot	1			3			1
Sanderling	14; 1	10	33	11; 6	12	25; 4	9
Dunlin	64; 1	62; 1	(56)	48	62	33; 8	60
Ruddy turnstone	6	8	8	6	2	5; 2	8
Arctic skua						2	
Long-tailed skua	13	9	14	4	21	12	6
Glaucous gull	11	11; 2	8	(7)	10	101	12
Arctic tern	3	9	1	3	8	6	2
Snowy owl					1; 3		
Northern weathear							3
Common raven	10	9	2	(5)	4	7	9
Snow bunting	104	64; 2	(54)	(30; 6)	110; 1	48; 10	116; 47

Table 3.26. Total number of birds recorded (adults; young) during line transect surveys through Store Sødal and from Daneborg to Zackenberg, mid-late July 1997-2003. Brackets denote interpolated figures.

Icelandic immatures began on 15 June. No indication of breeding was found this year. During 15 June to 10 July, a total of 2092 pink-footed geese was seen flying north with the highest numbers recorded on 16 June (644), 20 June (159) and 22 June (566). These high numbers of observations were partly due to the intensive effort by the Dutch team, who worked on the slopes of Aucellabjerg, which most of the geese pass. The average flock size was 23, the largest flock was 138. Several flocks were feeding in the area or seen flying around during the same period, and during the census of moulting geese on 16 July, a total of 40 pink-footed geese were found in four flocks east of the peninsula. One individual stayed together with the barnacle goose families in Kystkærene.

During the line transect through Store Sødal 17-19 July, a total of 38 pink-footed geese were found in four flocks of 1-14. 11 individuals were found at Store Sø, the rest in the upper part of the valley. This is a much lower figure than in the first years of our monitoring (see Table 3.26 and section above).

Besides a few scattered observations in the rest of July and August, a total of 113 individuals migrated south during the second half of August, and 120 were staging at Lomsø on 29 August.

Twelve pairs were incubating around the old Nanok trapping station on southernmost Hochstetter Forland on 3 June (Rasmus Gregersen, Sirius Dogsledge Patrol). Here, 11 pairs with nest were found in 1976 (Meltofte *et al.* 1981). Three pairs were encountered with at least 4-5 goslings at Revet on 10 July.

An old pink-footed goose leg with a British ring was found on fox den no. 10. It had been marked on 13 March 1998 as an adult (3k+) at Martin Mere, Lancashire.

Snow goose *Anser caeruscens*

On 5, 9 and 11 June, a white phase snow goose was seen together with barnacle geese, and on 12 June two white phase birds were seen together. On 28 July, 21 white birds were seen in a flock.

Barnacle goose *Branta leucopsis*

Up to 35 barnacle geese were seen almost daily during early and mid June. In the second half of the month, increasing numbers of immatures gathered at Lomsø, where 99 were counted on 22 June and 110 on 29 June. During the moult of immatures in July, up to 132 individuals were present at Lomsø, but late in the month they increasingly stayed on the coast, apparently partly as the result of wolf visits at Lomsø. During the goose census on 16 July, 120 individuals were present at Lomsø, nine were seen on the coast west of the peninsula and 30+6 were seen on the coast east of the peninsula.

About 20 individuals were found at Zackenbergelven a few kilometres north of the research station on 29 June, and they possibly moulted there. During the line transect through Store Sødal on 17-19 July, a total of 163 barnacle geese were recorded besides the families (see above). Most were found at Zackenbergelven below Store Sø (78) and in the innermost part of the valley (71).

In total, *c.* 369 immature barnacle geese moulted in the study area this year, which is very much the same as in most previous years. A further 20+27 individuals were encountered in inner Tyrolerfjord on 10 July.

From late July, when the immature geese increasingly regained flying capability, they also appeared in other parts of the valley in flocks of up to 136, probably including families. On 1 September, a flock of 80 migrated southwards high over the valley.

Common eider *Somateria mollissima*

When we flew up to Daneborg on 2 June, several hundred eiders were present on an open water area south of Kap Breusing. At Zackenberg, the first common eiders – a pair – appeared in the old delta on 12 June. From late June, up to 20 eiders were seen regularly on the open water off Zackenbergelven's delta and flying along the river.

The colony at Daneborg was censused by Rasmus Gregersen, Sirius Dogsledge Patrol, during 13-15 July. A total of 1364 active nests were counted, and a further 250-280 nests were estimated to have been deserted before the census, either because of predation by huskies on the females or because of earlier hatching. Hence, the first duckling appeared in the colony around 8 July. The resulting total of about 1600-1650 nests is much below estimates from previous years.

On 15 July, the first female with three ducklings was recorded on the coast at Zackenberg, and from then on, several family groups were found here until we left on 2 September. Peak numbers were six females with about 50 ducklings on 20 July and 52 females without young on 31 July.

Around 60-70 males and females were encountered during a trip through Tyrolerfjord and Rudis Bugt on 10 July. The last males were seen at Zackenberg on 16 July.

King eider *Somateria spectabilis*

2003 was a poor year for king eiders. The first king eider, a female, was recorded on 13 June, which is well within the range from previous years (Table 3.27). Only one pair was seen a few times during late June (Table 3.16), besides four and five females on the coast on 23 and 24 July, respectively.

Long-tailed duck *Clangula hyemalis*

In accordance with the late ice melt on the ponds, the first pair of long-tailed ducks were seen on 7 June. This is as late as recorded before (Table 3.27). Numbers increased fast, and already on 11 June seven pairs and two single males were present.

On 17 June, a nest with two eggs was found, and on 22 June it held six deserted eggs. On 15 and 20 July, the remains of depredated nests were found south of the runway and south of the research station, respectively.

From 20 June, long-tailed ducks were also seen in Zackenbergelven's delta, and from 15 July flocks of up to 21 individuals were counted in Lomsø and along the coast. No broods were seen.

Gyr falcon *Falco rusticolus*

On 12 June, a pair of immature gyr falcons were seen mating, and on the next day one was seen. In July and August, three records of single individuals were made, one of the birds trying to catch adult and young common eiders.

Rock ptarmigan *Lagopus mutus*

During June, the remains of a total of 10 predated ptarmigans in winter plumage was found, eight of them on or close to fox den no. 1.

On 30 June, the first live – male – ptarmigan was seen on the slopes of Zackenberg, and another male was seen west of the bird census area on 15 July. Furthermore, two broods were found, one with 11

Table 3.27. Dates of first observation of selected species at Zackenberg 1996-2003.

	1996	1997	1998	1999	2000	2001	2002	2003
Red-throated diver	<3.6	30.5	3.6	4.6	6.6	3.6	1.6	<4.6
King eider	12.6	4.6	15.6	16.6	22.6	9.6	11.6	<13.6
Long-tailed duck	<1.6	30.5	2.6	6.6	6.6	7.6	3.6	7.6
Red-necked phalarope	5.6	30.5	5.6	10.6	7.6	4.6	5.6	11.6

chicks 250 m a.s.l. on Aucellabjerg 29 July and another with three large chicks 180 m a.s.l. on the slopes of Zackenberg 4 August. On Zackenberg, an old hatched nest was found 400 m a.s.l.

Waders Charadrii

The only pre-breeding group of waders was four common ringed plovers *Charadrius hiaticula* on 9 June. On 3 June, a light-plumaged immature red knot *Calidris canutus* was seen.

Post-breeding flocks were seen inland from late June, with 12 sanderligs *Calidris alba* and nine knots in early July as the largest. During waterbird counts in the deltas from late July to late August, peak numbers of adult waders were 34 ringed plovers on 1 August, 32 sanderlings on 4 August, 79 dunlins *Calidris alpina* on 29 July and 18 ruddy turnstones *Arenaria interpres* on 19 July. Similarly, peak numbers of juveniles were 74 ringed plovers on 13 August, three knots on 13 August, 35 sanderlings on 4 August, 60 dunlins on 16 August and 18 turnstones on 28 August.

This year, three wader rings were controlled during catching by the Dutch team. On 21 June, a one-year-old female turnstone was caught on the nest. It had been ringed in West-Vlaanderen, Belgium, on 28 February the same year. On 10 July, an incubating knot was caught, which had been ringed at the Wash, U.K., on 19 January 1991. Hence, it was at least 14 years old when caught at Zackenberg. Colour bands were added, and the bird was seen again near the island of Terschelling in the Dutch Wadden Sea on 4 October 2003. On 26 July, an adult sanderling with three chicks was carrying a ring, which was put on it as an eight days old chick on 23 July 1997 1500 m from where it was found with chicks itself. Two other knots colour marked at Zackenberg this summer by the Dutch team were seen at the Wash, U.K., on 28 November 2003 and 8 January 2004, respectively. Furthermore, on 30 September 2003 a Danish type ring on a Sanderling at Tarifa in southernmost Spain very likely from a chick ringed at Zackenberg on 8 July 2003 (no. <u>8</u>2<u>23005</u>; digits read by Ole Thorup underlined).

Red-necked phalarope *Phalaropus lobatus*

The first red-necked phalarope – a male – was seen as late as 11 June, which is in accordance with the late ice melt (Table 3.27). On 15 June, two males were present, and on the next day even a female. All three birds were seen on the ponds around the research station until 22 June and then again a pair on 7 July. On 11 July a male was giving alarm calls and showing anxious behaviour in eastern Sydkærene. None were seen later.

Red phalarope *Phalaropus fulicarius*

Both on 6 and 9 June, a female red phalarope was seen on the ponds around the research station, and a juvenile was seen at Sandøen on 15 August (Magnus Elander *in litt.*).

Pomarine skua *Stercorarius pomarinus*

One adult dark phase pomarine skua was seen at Sandøen on 20 August (Magnus Elander *in litt.*).

Arctic skua *Stercorarius parasiticus*

Two adult light phase arctic skuas were seen at Sandøen on 20 August (Magnus Elander *in litt.*), and on 28 and 29 August, one and two light phase adults, respectively, were seen at the old delta of Zackenbergelven.

Long-tailed skua *Stercorarius longicaudus*

From 30 June, the long-tailed skuas started to gather in display groups, and during July true flocks formed peaking with 16 on 11 and 12 July and 17 on 23 July. Among these flocks, but also alone, apparently two-year-old immatures were seen on 1 and 23 July, and apparently one-year-old immatures were seen on 4, 10, 16 and 29 July – one at each occasion. On 10 July, the one-year-old immature was together with an adult pair; one of them giving alarm calls as if with a newly fledged juvenile. The 'family' was found west of the river, where four pairs fledged one young each in 2002 (Rasch and Caning 2003).

On 9 July, 14 individuals were feeding on the exposed tidal flat east of the peninsula. At two occasions, adult long-tailed skuas were seen eating young waders, and two adults were seen chasing a common ringed plover. This may be related to the scarcity of lemmings. Most unsuccessful adults left from late July, and the last record was of one of the juveniles on 22 August (see section above on Reproductive phenology and success in long-tailed skuas).

On 7 July, an adult long-tailed skua was caught with a ring, placed on it exactly six years earlier only 500 m away, already an adult breeder.

Lesser black-backed gull *Larus fuscus*
An adult lesser black-backed gull was seen at Lomsø on 20 June. See also section above on Sandøen.

Glaucous gull *Larus hyperboreus*
Five glaucous gulls migrated north through the valley on 4 June, whereupon up to four were seen almost daily during June. On 29 June, the first immature was seen. In early July, up to 32 individuals were present in Zackenbergelven's delta, with lower numbers during the rest of July and August (incl. one immature most of the time). From 20 August, up to four juveniles and three immatures also occurred.

Black-legged kittiwake *Rissa tridactyla*
During 15-20 August, 200-300 kittiwakes were present around Sandøen (Magnus Elander *in litt.*). At Zackenberg, 10 adults and four juveniles were recorded on 28 August.

Arctic tern *Sterna paradisaea*
On 28 August, 32 arctic terns were recorded off Zackenberg (see also section above on Sandøen).

Black tern *Chlidonias niger*
A black tern was seen together with arctic terns at a pool on Sandøen on 14 August (Magnus Elander and Ian Gjertz *in litt.*). The bird was in full adult breeding plumage and was mobbed by the arctic terns and Sabine's gulls. After half an hour of observation, the bird left to the southwest.

This is the first record of the species in Greenland (cf. Boertmann 1994). The closest breeding grounds are in Denmark and the Netherlands, but it also breeds in central North America.

Northern weathear *Oenanthe oenanthe*
The only weathears recorded this year, were a pair and a single individual seen during the line transect between Daneborg and Zackenberg on 16 July. See section on Line transects above.

Common raven *Corvus corax*
During June, one or two ravens were seen regularly. From 1 July, three juveniles also appeared, and on 13 August, 10 individuals were recorded.

Arctic redpoll *Carduelis hornemanni*
During 12 June – 6 July, single redpolls were seen regularly flying over the valley – often singing. On 20 June a pair mated 600 m a.s.l. on Zackenberg, and on the next day a pair was feeding and singing in the western part of the bird census area. On 4 August, a juvenile was encountered 300 m a.s.l. on Zackenberg, and a flock of 20 was seen 650 m a.s.l. on Aucellabjerg on 25 August.

Snow bunting *Plectrophenax nivalis*
The first juvenile snow bunting was seen at the river crossing on 10 July, and from late July, many were found all over the area. Flocks of up to 30 individuals were seen from mid August.

3.4 Mammals

Thomas B. Berg

Observations on mammals were made by Hans Meltofte (1 June – 5 August), Line A. Kyhn (1 June – 2 September) and Thomas B. Berg (26 June – 2 September). Most other personnel supplied additional random observations during the entire field season. The census area for collared lemming was surveyed for winter nests during 28 June – 12 August. Total number of musk oxen including age and sex data were censused once a week within the 40 km^2 musk ox census area during 2 July – 27 August. During the entire season, additional counts were made from the roof of a house on the research station (between 20:00 and 23:00) scanning the coastland and mountain slopes from Tyrolerfjord to Lille Sødal north of Daneborg whenever weather conditions permitted. During these counts, arctic hares on the east-facing slope of Zackenberg mountain were also recorded. Similarly, number of seals on the fjord ice in Young Sund were recorded until the ice became too fragmented on 5 July.

The line transect Daneborg – Zackenberg was walked by Line A. Kyhn and Thomas B. Berg during 16 July, and the transect Zackenberg – Store Sødal was walked during 17-19 July by the same persons.

As an adjustment to the BioBasis protocol on monitoring of arctic fox dens, all dens within the musk ox census area were visited once a week. All ten known fox dens within the 50 km^2 fox study area and one just outside the eastern border (Kuhnelv) were checked regularly for occupation, and the only den known between Daneborg and Kuhnelv was checked on 16 July. All observations other than those on lemmings, foxes and musk oxen are presented in the section on Other observations, where scientific names for all species are also given.

Collared lemming population

A total of 96 fresh winter nests was recorded within the 2.05 km^2 census area (Table 3.28). Following the intermediate winter population densities of 2000-2002, the population crashed to the lowest level since the start of the BioBasis programme in 1995. Only one lemming was observed by Hans Meltofte during bird censuses in June and July (Table 3.28). While the number of winter nests recorded during the line transect through Store Sødal was close to the past two years of intermediate winter nest density within the 2.05 km^2 census area, the number recorded on the transect Daneborg – Zackenberg equalled the winter nest density within the census area during the low phase in 1999 (Table 3.29).

At Karupelv, 220 km south of Zackenberg, the lemming population reached a minimum as well, and it is most noteworthy that the patterns have been quite parallel on the two sites for nine years now, including the ‘amputated’ 2001-2002 ‘peak’ (Figure 3.4). Also numbers of lemming winter nests depredated by stoat dropped to a minimum at both Zackenberg and Karupelv (Figure 3.4).

The 29 fixed sampling sites for predator casts and scats were checked on 26 August (Table 3.30). In general the numbers of scats and casts were among the lowest recorded so far. Especially the number of cast from skua was only half the number of the last minimum.

Musk ox population biology

The daily censuses of musk ox densities in Zackenbergdalen and on adjacent slopes from a fixed point at the station followed the average pattern of 1996-2002 (Figure 3.5). Numbers of ’musk ox days’ (one animal in one day) within the 40 km^2 census area were the lowest recorded in June. On the other hand, including the areas visible outside the census area the daily numbers of musk oxen were above average, only exceeded by 2001 and 2002 (Figure 3.5). In August, the number of ’musk ox days’ inside the census area was the second highest ever recorded (Table 3.31). The maximum number of musk oxen recorded within the 40 km^2 census area on the weekly censuses was 111 individuals on 27 August, while the maximum count of 137 musk oxen within the visible area (135 km^2 in total) was made on 13 August.

	Winter nests category 1	Winter nests category 2	Animals seen
1995	285	821	-
1996	161	263	0
1997	342	109	1
1998	711	109	43
1999	305	57	9
2000	184	70	1
2001	318	22	11
2002	311	29	4
2003	96	31	1

Table 3.28. Annual number of recorded winter nests and summer burrows within the 2.05 km^2 census area in Zackenbergdalen 1995-2003 together with the number of animals encountered by one person (same effort each year) within the 19 km^2 bird census area during June-July. Category 1 denotes nests from the previous winter, category 2 are nests from earlier winters that were not recorded previously.

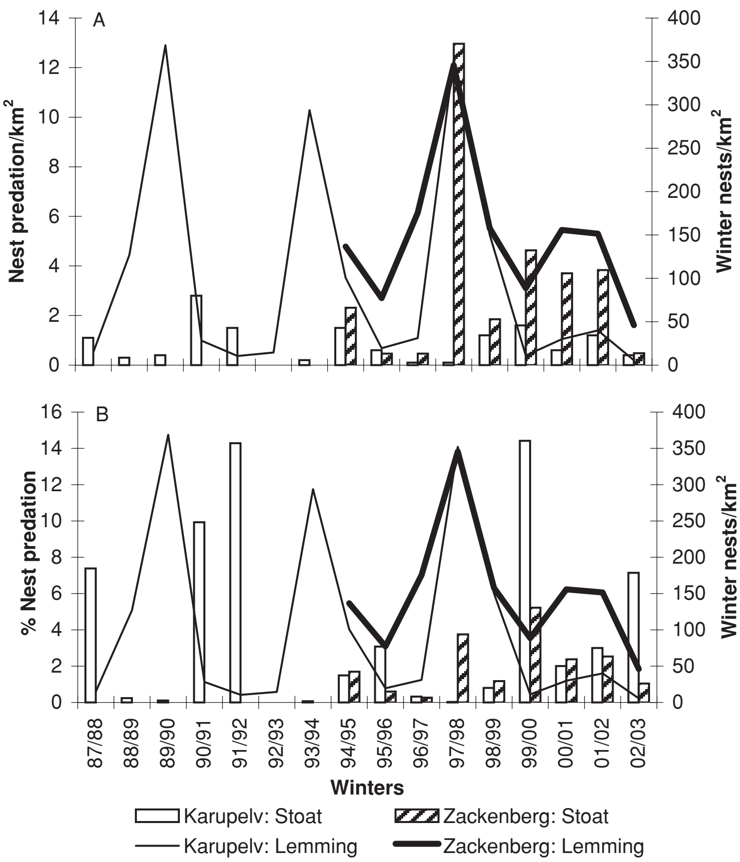


Figure 3.4. Lemming winter nests (right axis) and stoat predation on lemming nests (left axis) at Karupelv, Traill Ø (10 km^2; c. 220 km south of Zackenberg) and within the census area in Zackenbergdalen (2.05 km^2). Data include nests built from October to May. Nest predation by stoat is given in actual number of depredated nests (A) and as percent of total number of lemming nests (B). Benoît Sittler kindly provided data from Karupelv (partly published in Sittler 1995, 2003).

Table 3.29. Lemming winter nests recorded along the transects Zackenberg – Store Sødal (65 km) and Daneborg – Zackenberg (20 km) 1996-2003. Nests and burrows were recorded within 3 m on each side of the two observers, giving a total transect length of 130 km and 40 km, respectively. Deviations are indicated in the table.

	Distance	Winter nests	
	km	No.	No./km
Store Sødal			
1996	150	2	0.013
1997	300	11	0.067
1998	150	21	0.140
1999	130	3	0.023
2000	130	1	0.008
2001	130	13	0.100
2002	130	9	0.069
2003	130	12	0.092
Daneborg - Zackenberg			
1997	50	22	0.440
1998	50	17	0.340
1999	40	1	0,025
2000	40	0	0
2001	40	24	0.600
2002	40	5	0,125
2003	40	1	0,025

Table 3.30. Numbers of casts and scats from predators collected from 29 permanent sites within the 2.05 km² lemming census area in Zackenbergdalen. The samples represent the period from mid/late August the previous year to August in the year denoted.

	Skua casts	Owl casts	Fox scats	Stoat scats
1997	44	0	10	1
1998	69	9	46	3
1999	31	3	22	6
2000	33	2	31	0
2001	39	2	38	3
2002	32	6	67	16
2003	16	0	20	1

Table 3.31. Accumulated number of 'musk ox days' per month counted as one musk ox in one day within the 40 km² census area in Zackenbergdalen based on the daily counts from a fixed elevated point at the research station 1996-2003.

	June	July	August	Total
1996	445	445	2412	3302
1997	290	1086	1432	2807
1998	522	635	1121	2278
1999	361	392	1292	2045
2000	478	898	1543	2919
2001	922	1257	1689	3868
2002	418	448	1819	2684
2003	287	638	2247	3172

During the two transects Daneborg – Zackenberg (DZ) and Zackenberg – Store Sødal (ZS) 16-19 July and the affiliated weekly census, a total of 109 different musk oxen were recorded, which is close to the minimum recorded in 1997 (Table 3.32). According to the records from the line transects, the proportion of calves was 16.5% in 2003 (range 1997-2003: 9-17%) and close to one calf per two cows (Table 3.33). Furthermore, these records showed a fairly constant proportion of cows (33.9-42.7%) over the years (Table 3.33). On the contrary, the two years old subadults together with the adult bulls are those age classes that show the greatest year to year variation in density. Data on musk ox observations from the line transects are presented in condensed form for year to year comparison in Table 3.34. The number of faeces piles in Store Sødal were remarkably high (winter piles: 9.6 / km; summer piles: 3.1 / km), indicating that these inland areas had been used more intensively than average (mean ± 95% CI, 5.0 ± 2.8 and 1.4 ± 0.9 respectively).

Using the August data from the weekly censuses within the 40 km² census area the number of cows without a calf (*i.e.* the minimum number of cows with a reproductive potential) was 70% in 2002, which was above the previous seven years average of 54% (range 42-83%). Only 42% of these seem to have given birth to a calf that was still alive in August 2003 (average of 1997-2002 60.4%, range 29.6-120.5%). The snow cover by 10 June reflecting the amount of snow during the calving period seems to have a pronounced effect on the calf-cow ratio in August in that the two years with a particularly high calf-cow ratio – 2000 and 2002 – also had the least extensive snow cover (Figure 3.6). There are, however, other factors affecting the number of calves, such as heavy ice crusting during winter. Without individual marked cows one should be cautious in drawing conclusions.

Two fresh musk ox carcasses were found inside the 40 km² census area, and one additional outside the area on Palnatoke Bjerg (Table 3.35). The two carcasses inside the census area were of one old bull (app. 10+ years) that was scavenged by arctic fox, and a calf of unknown sex with only the vertebrae remaining. The old bull (app. 15+ years old) found on the slopes of Palnatoke Bjerg died between 23 and 31 July. There was no sign of predators. The whole carcass was filled with gas, and the snout showed a light green colour. A raven was seen on the carcass, but the eyes were still untouched, indicating that it had been dead for only a short while. The variation in numbers of musk ox carcasses from year to year is presented in Table 3.36.

Arctic fox dens

2003 showed a peak number of 17 arctic fox pups (all white colour phase) within the 50 km² study area, which is remarkably high considering the record low number of lemming winter nests and the low number of musk ox carcasses. On the other hand several kills of rock ptarmigan in winter plumage were recorded (see Rock ptarmigan in section 3.4). The high number of pups recorded in 2003 compared to previous years could at least partly be the result of the research project on foxes this year (see section 5.7). In order to secure better data on fox pups, all fox dens will be checked once a week in the future.

Six dens within the study area were used regularly during the summer (nos 1, 2, 3, 4, 5 and 10), and additionally two dens were visited at irregular intervals (nos 6 and 8) (Table 3.37). Of the six dens, three were used for breeding (nos 1, 5 and 10). Last time pups were recorded at these dens was on 3 July, 11 August, and 13 August, respectively. By the time the pups began to explore their surroundings at greater distances, pups were recorded at den no. 2 (first record 11 July, last record 6 August), den no. 3 (first record 7 July, last record 4 August). An additional hole was recorded at den no. 5 situated down-slope *c.* 45m SW of the maternal den. A new den consisting of only one hole was found south of den no. 2 on top of the riverbank on the western side of Kærelv.

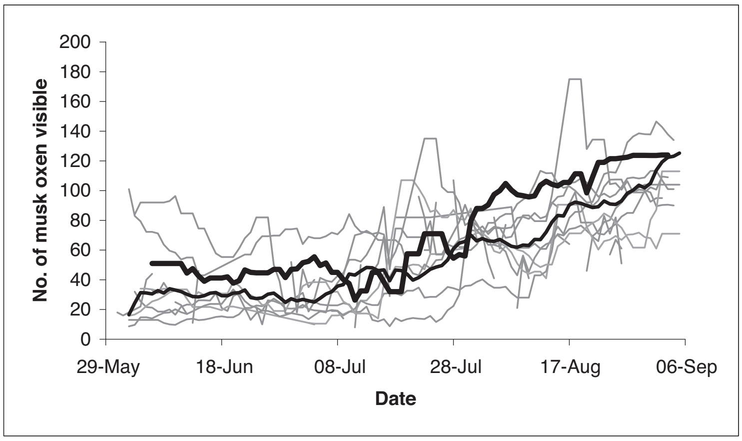


Figure 3.5. The number of musk oxen (one week running means) recorded daily in 2003 from a fixed elevated point at the research station is shown with a heavy thick line, the mean values of 1995-2002 with a thick line, and data from previous years with thin lines. The visible area is c. 135 km².

Other observations

Collared lemming *Dicrostonyx groenlandicus*

Only two lemmings were encountered in the field clearly illustrating the low lemming density.

	Calf	F1	M1	F2	M2	F3	M3	F4+	M4+	Total
1997	13	5	6	13	14	8	2	32	10	103
1998	11	6	7	8	8	8	7	44	23	122
1999	24	0	0	9	8	13	7	58	52	171
2000	25	6	7	4	1	7	6	47	44	147
2001	27	10	7	6	7	6	1	58	38	160
2002	21	10	9	12	10	10	4	57	40	173
2003	18	6	7	3	5	3	4	34	29	109

Table 3.32. Sex and age distribution (actual numbers) of musk oxen based on total counts along the two line transects and the related total census in Zackenbergdalen 1997-2003. All counts were made within 16-30 July and covered an area of about 200 km². Double counts have been omitted.

	Calf/cow	1 yr/cow	2 yrs/cow	Calf	1 yr	2 yrs	3 yrs male	Ad. female	Ad. male	Ad. 4+yrs	Total
1997	0.32	0.28	0.67	12,6	10.7	26.2	1.9	38.9	9.7	40.8	103
1998	0.25	0.29	0.37	9.0	10.6	13.2	5.7	42.7	18.9	55.0	122
1999	0.41	0.0	0.29	14.0	0.0	10.0	4.1	41.5	30.4	64.3	171
2000	0.53	0.28	0.11	17.0	8.9	3.4	4.1	36.8	29.9	61.9	147
2001	0.46	0.29	0.23	16.8	10.7	8.2	0.6	40.1	23.8	60.1	160
2002	0.37	0.33	0.39	12.1	11.0	12.7	2.3	38.7	23.1	56.1	173
2003	0.49	0.35	0.22	16.5	11.9	7.3	3.7	33.9	26.6	57.8	109

Table 3.33. Proportions of calves, one and two year old subadults in relation to adult cows (three years or older; first three columns), together with the sex and age distribution (per cent) of musk oxen based on total counts along the two line transects and the related total census in Zackenbergdalen 1997-2003. All counts were made within 16-30 July and covered an area of 200 km². Double counts have been omitted.

Table 3.34. Musk ox densities (animals/km^2) in Store Sødal (census area was 92 km^2 1996-1998 and 125 km^2 from 1999), Zackenbergdalen (40 km^2) and in the coastal region between Daneborg and Zackenberg (37 km^2) in mid/late July 1996-2003. The density of faeces piles (no. of piles/km walked) in Store Sødal (census area was 150 km 1997-1998 and 130 km from 1999) and from Daneborg to Zackenberg (40 km).

	Store Sødal	Zackenberg-dalen	Daneborg - Zackenberg	Snow cover (%) Zackenberg 10 June
Musk oxen/km^2				
1996	0.37	0.33	-	77
1997	0.39	1.58	0.13	81
1998	0.62	1.18	0.86	80
1999	0.78	1.20	0.70	92
2000	0.25	2.10	0.22	54
2001	0.31	3.38	0.92	82
2002	0.69	1.68	0.30	77
2003	0.26	1.70	0.22	83
Faeces piles/km				
1997 winter/summer	1.91 / 0.59	-	6.13 / 1.03	81
1998 winter/summer	1.86 / 0.47	-	1.43 / 0.85	80
1999 winter/summer	7.42 / 1.93	-	4.58 / 3.08	92
2000 winter/summer	2.76 / 0.45	-	1.13 / 0.28	54
2001 winter/summer	6.57 / 1.32	-	2.63 / 0.45	82
2002 winter/summer	4.93 / 1.81	-	4.73 / 0.60	77
2003 winter/summer	9.58 / 3.08	-	3.70 / 0.68	83

ID. no.	UTM East	UTM North	Sex	Estim. age	Remarks
2003-1	512514	8266828	M	10+	Lying on right side, no bended legs. No sign of wolf. Eaten by fox
2003-2	512233	8272069	M	15+	Died 23 - 31 July. No sign of kill. Belly filled with gas. Part of nose skin dyed green
2003-3	515145	8269717		Calf	Only vertebrae left.

Table 3.35. Fresh musk ox carcasses found 2003.

Polar bear *Ursus maritimus*

On 20 August, a big male was encountered by a Nanok team on the south side of Clavering Ø. A female with two pups were recorded going south along the outer coast of Wollaston Forland on 22 August by researchers from Daneborg. The bears fled upward on the very steep mountain slope and kept the altitude while returning towards the north. The family was relocated when the research team returned towards Daneborg, and the same behaviour by the bears was seen.

Arctic wolf *Canis lupus*

The first tracks were found on 4 June west of Zackenbergelven close to the river passage. Fox den no. 2 was visited during mid June, and dens nos 3 and 10 were visited during the end of August. Towards the end of June tracks were found along the coast between the two deltas. A lonely adult individual was seen on 10 July, when it came up from the delta and passed the eastern end of the airstrip and continued to fox dens nos 3 and 4. In the early morning of 5 August a wolf visited the station unseen, but left fresh tracks.

Arctic fox *Alopex lagopus*

A special study on arctic foxes took place in 2003 (see section 5.7), and the second highest number of foxes (50) were encountered in the terrain (away for dens; Table

	Snow cover 10 June (%)	Thaw days	Total carcasses	4+ yrs F / M	3 yrs F / M	2 yrs F / M	1 yr F / M	Calf
1994-1995	76	?	2	0 / 1				1
1995-1996	77	5	13	7 / 1	0 / 1	0 / 2	1 / 1	
1996-1997	81	3	5	0 / 2		1 / 0	1 / 0	1
1997-1998	80	6	2	0 / 2				
1998-1999	92	5	1	0 / 1				
1999-2000	54	3	8	0 / 6	1 / 0			1
2000-2001	82	0	4	0 / 4				
2001-2002	77	1	5	1 / 2	1 / 0			1
2002-2003	83	9	2	0 / 1				1

Table 3.36. Fresh musk ox carcasses found 1995-2003. F = female, M = male. 'Thaw days' is the number of days October-April when the snow cover (>5 cm) is exposed to positive temperatures, which may cause ice crust.

3.38). Based on trapped and radio collared foxes, moult patterns, colour and geographic position of observations, it is estimated that a minimum of five adult white phase foxes stayed within the 50 km^2 main study area. As arctic foxes raise their pups in families with both parents, it is most likely that there were six adults in total, since there were three breeding dens within the area. Between one and three pups from either den no. 5 or 10 were recorded five times on Ulvehøj from 7 until 27 August.

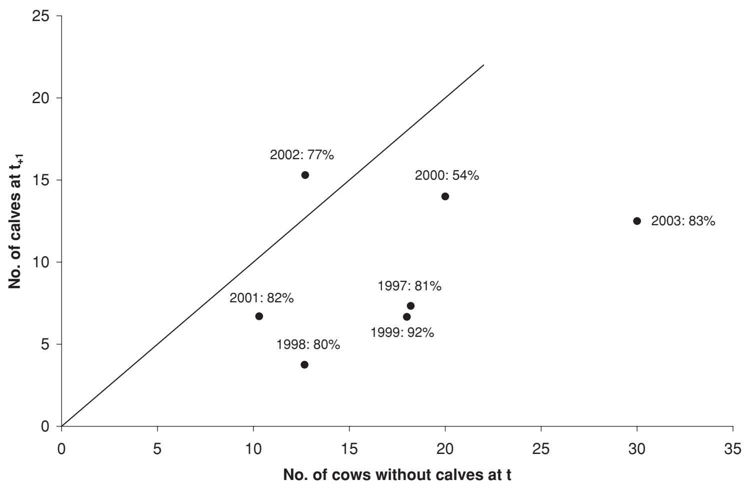


Figure 3.6. Average number of calves during the weekly censuses in August plotted against the number of cows without calves in August the previous year (total number of cows (3 years or older) minus the number of calves). The line represents the 1:1 ratio. The per cent values denote the snow cover in Zackenbergdalen on 10 June of the given year.

Arctic hare *Lepus arcticus*

Many tracks were recorded at the station upon our arrival on 27 May. Daily records of arctic hares were made whenever weather permitted during 30 June – 28 August, when the east facing slope of the Zackenberg mountain was searched by means of a 30x spotting scope. A mean of 4.35 animals was recorded per count (N=20), and the maximum of 13 exceeded the previous maximum of 11 from 1999 (Table 3.39). The animals were distributed between 30 and 830 m a.s.l. (mean 300 m). Additional counts from the station gave two groups of two and additional three individuals on the slopes of Aucellabjerg. In addition to these counts, a total of 39 adults and three juveniles were encountered in the field on the western side of Zackenbergelven and near the top of Aucella. In total this sum up to a minimum of 13 individuals west of Zackenbergelven and five on Aucellabjerg excluding possible double counts.

Stoat *Mustela erminea*

One adult was seen at Nansenblokken on 1 July and one near Permdal on 16 July. Tracks were recorded near Nordvestkæret and fresh digging by stoat was found inside two different entrances in fox den no. 2.

Walrus *Odobenus rosmarus*

The maximum number of walruses this year on Sandøen was 37 on 1 and 2 August (see section 5.9).

Seals Phocidae sp.

Seals on the fjord ice were recorded during the daily musk ox counts from 1 June until the fjord ice became too fragmented on 5 July. 12 counts were made with an average of 64 seals per census and a maximum of 126 on 30 June (Table 3.40). This is more than twice the number recorded at the past high record from 1999.

	No. of known dens inside/outside	No. of dens in use inside/outside	No. of breed. dens inside/outside	Total no. of pups recorded	No of muskox carcasses	Lemming winter population
1995	2/0	0/0	0/0	0	2	decrease
1996	5/0	4/0	2/0	5W + 4D	13	low
1997	5/0	1/0	0/0	0	5	increase
1998	5/0	2/0	1/0	8W	2	peak
1999	7/0	3/0	0/0	0	1	decrease
2000	8/0	4/0	3/0	7W	8	low
2001	10/2	6/1	3/1	12W + 1D	4	increase
2002	10/2	5/1	1?/0	0	4	intermediate
2003	11/2	8/1	3/0	17W	2	low

Table 3.37. Number of known fox dens in use, number with pups and the total number of pups recorded at their maternal dens within the 50 km^2 fox census area in Zackenbergdalen. 'W' and 'D' denote white and dark colour phase.

	White phase adult	White phase juvenile	Dark phase adult	Dark phase juvenile	Total number of records	Number of fox carcasses
1996	3	5	1	0	31W + 3D	
1997	2	1	1	0	17W + 5D	1W + 1D
1998	3	1	1	2	21W + 3D	1W
1999	3-4	0	1	0	18W + 1D	2W
2000	5-6	3	0	0	28W	2W
2001	3	4-5	1	1	54W +1D	1W
2002	2	0	0	0	23W	0
2003	5	17	0	0	50W	0

Table 3.38. Minimum numbers of individual foxes recorded in Zackenbergdalen (50 km^2, 1 June - 31 August) divided into colour phases (W = white; D = Dark) and age classes 1996-2003, excluding pups at dens. "Total number of records" gives the number of records of all adults and those of juveniles encountered in the field away from their maternal den. Also foxes visiting the research station are included. See Table 3.21 for observations in June-July.

	Average+ SD	Range	Counts	Others
2000	2.78 +2.90	0-11	16	67
2001	2.36 +1.71	0-6	22	72
2002	1.06 +0.28	0-4	16	19
2003	4.35 +0.65	0-13	20	42

Table 3.39. Arctic hares appearing on the east facing slope of Zackenberg mountain during the daily counts from a fixed point at the research station 1 July – 31 August 2000-2003. "Others" denote additional records from the field.

	Average+SD	Range	Counts
1997	8.52+4.98	3 - 21	23
1998	7.42+4.50	0 - 18	18
1999	25.05+12.32	2 - 61	22
2000	14.38+7.00	2 - 28	16
2001	22.06+14.22	3 - 57	16
2002	28.68+3.82	9 - 48	13
2003	63.58+32.09	14 -126	12

Table 3.40. Numbers of seals counted daily from a fixed point at the research station from 1 June until the fjord ice became too fragmented in early/mid July 1997-2003. Counts were only made when visibility was good.

Lake	SS	SS	SS	LS	LS	LS
Date	26.7	7.8	18.8	26.7	7.8	18.8
Ice cover (%)	0	0	0	0	0	0
Temperature (°C)	11.7	12.4	9.0	12.4	12.0	8.9
pH	6.5	6.5	6.5	6.0	6.1	6.3
Conductivity (µS/cm)	8	12	16	5	7	7
Chlorophyll a (µg/l)	1.34	1.00	3.17	3.02	2.97	3.43
Total nitrogen (µg/l)	300	280	250	210	250	250
Total phosphorous (µg/l)	13	9	11	9	9	11

Table 3.41. Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July and August 2003.

3.5 Lakes

Kirsten Christoffersen and Erik Jeppesen

The unusually warm summer of 2003 was clearly reflected in the environmental conditions of Sommerfuglesø and Langemandssø. Both lakes were ice-free from the beginning of July, and an estimated ice cover of 50% occurred around 24 June in Sommerfuglesø and around 2 July in Langemandssø (Table 3.42). An earlier ice-out has only been recorded in 2000, a year of very little snow cover.

The standard sampling programme was conducted between 26 July and 18 August with about 10-days intervals between the three samplings. Water temperatures were constantly high (9-12ºC), the mean temperature being 11ºC in both lakes (Tables 4.41 and 4.42). Despite the early ice-out the average values recorded for conductivity, total nitrogen and total phosphorus were within the range from previous years (Tables 4.41. and 4.42).

Among the phytoplankton species, chrysophytes dominated in both lakes, with 89% and 74% of the biovolume in Sommerfuglesø and Langemandssø, respectively (Table 4.43). The predominant genus in both lakes was *Uroglena* spp., but also *Dinobryon bavaricum*, *D. hilliardii*, *Kephyrion boreale* and *Ochromonas* spp. were recorded, though in lesser amounts. The remaining biomass was made up of the dinoflagellates *Gymnodinium* spp. and *Peridinium* spp., the diatom species *Tabellaria* spp. and green algae such as *Cosmarium* spp. and *Staurastrum* spp. The species composition and dominance of chrysophytes resembles other 'warm' summers (Table 3.44).

The average phytoplankton biomass in terms of chlorophyll *a* reached the highest level recorded during the seven years of monitoring and was even higher than the high level recorded in 2002, which was also characterised by an early ice-melt (Rasch and Caning 2003). The average concentrations were 1.84 and 3.14 µg/l in Sommerfuglesø and Langemandssø, respectively (Table 3.42), and represent increases of 44% and 15% compared to 2002. The higher phytoplankton biomass was not reflected by increases in total phosphorous and total nitrogen concentrations, however.

The zooplankton community was sam-

Lake	SS 1997	SS 1998	SS 1999	SS 2000	SS 2001	SS 2002	SS 2003	LS 1997	LS 1998	LS 1999	LS 2000	LS 2001	LS 2002	LS 2003
Date of 50% ice cover	ND	11.7	18.7	24.6	2.7	3.7	24.6	ND	23.7	21.7	30.6	8.7	6.7	2.7
Temperature (°C)	6.3	6.5	6.1	10.1	8.4	8.3	11.0	6.8	6.4	4.0	9.5	8.4	8.1	11.1
pH	6.5	7.4	6.7	5.8	6.6	6.0	6.5	6.5	7.0	6.3	5.5	6.4	5.5	6.1
Conductivity (µS/cm)	15	13	10	18	18	8	12	8	9	7	9	8	6	6
Chlorophyll a (µg/l)	0.84	0.24	0.41	0.76	0.67	1.27	1.84	1.04	0.32	0.38	0.90	1.46	2.72	3.14
Total nitrogen (µg/l)	ND	130	210	510	350	338	277	ND	80	120	290	340	387	237
Total phosphorous (µg/l)	4	9	11	10	19	11	11	8	7	7	11	20	13	10

Table 3.42. Average physico-chemical variables in Sommerfuglesø (SS) and Langemandssø (LS) 1999-2003 (July-August) compared to single values from mid-August 1997 and 1998. ND = no data.

Lake Date	SS 26.7	SS 7.8	SS 18.8	LS 26.7	LS 7.8	LS 18.8
Nostocophyceae	0	0.000	0	0	0	0
Dinophyceae	0.018	0.030	0.032	0.115	0.182	0.072
Chrysophyceae	0.044	0.189	0.476	0.395	0.567	0.112
Diatomophyceae	0.000	0.001	0.000	0.000	0.000	0.000
Chlorophyceae	0.003	0.002	0.002	0	0.006	0.004
Others	0.000	0.000	0.000	0.000	0.000	0.000
Total	0.065	0.222	0.510	0.510	0.755	0.188

Table 3.43. Biovolume (mm^3/l) of phytoplankton species in Sommerfuglesø and Langemandssø July-August 2003. 0 = no individuals, 0.000 = <0.0005 mm^3/l.

Lake	SS 1998	SS 1999	SS 2001	SS 2002	SS 2003	LS 1997	LS 1998	LS 1999	LS 2001	LS 2002	LS 2003
Nostocophyceae	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dinophyceae	0.034	0.044	0.015	0.006	0.027	0.291	0.185	0.305	0.040	0.156	0.123
Chrysophyceae	0.022	0.096	0.358	0.066	0.237	0.066	0.187	0.048	0.592	0.377	0.358
Diatomophyceae	0.002	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000
Chlorophyceae	0.005	0.002	0.000	0.000	0.002	0.016	0.000	0.002	0.002	0.000	0.003
Others	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	0.063	0.147	0.378	0.072	0.266	0.375	0.372	0.355	0.636	0.533	0.484

Table 3.44. Average biovolume (mm^3/l) of phytoplankton species in Sommerfuglesø and Langemandssø 1997-2003 (except for 2000).

Lake	SS 1997	SS 1998	SS 1999	SS 2000	SS 2001	SS 2002	SS 2003	LS 1997	LS 1998	LS 1999	LS 2000	LS 2001	LS 2002	LS 2003
Cladocera														
Daphnia pulex	0.3	10.5	0.3	6.7	8.2	6.8	7.7	0	0	0	0	0	0	0.1
Macrothrix hirsuiticornis	0.1	0	0	0	0	0	0	0	0	0.2	0	0	0	0.0
Chydorus sphaericus	0.05	0	0	0	0.06	0	0	0	0.1	0	0.5	0.1	0.07	0.00
Copepoda														
Cyclops abyssorum alpinus (adult+copepodites)	0.8	0.5	0.5	0.3	0.5	0.2	0.9	3.3	2.9	4.1	22.0	13.4	6.8	8.6
Nauplii	5.7	1.3	6.5	1.1	1.4	2.3	0.3	5.2	3.8	6.4	3.1	4.5	4.5	4.2
Rotifera														
Polyarthra dolicopthera	171	90	185	97	74	11	0.5	316	330	274	168	248	22	78
Keratella quadrata group	4.5	3	17	0	0	0.4	0.1	4.5	28	34	0	0	0.3	0.0
Conochilus sp.	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0

Table 3.45. Density (no/l) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) in mid-August 1997-2003.

	Temperature (°C)	pH	Conductivity (µS/cm)	Total phosphorus (µg/l)	Total nitrogen (µg/l)	Chlorophyll *a* (µg/l)
1997	8.7 (1.9)	6.8 (0.4)	21 (17)	10 (6)	314 (182)	1.8 (1.2)
2003	11.4 (1.1)	6.4 (0.2)	17 (12)	14 (8)	298 (213)	2.5 (1.5)

Table 3.46. Average values of temperature, pH, conductivity, total phosphorous and chlorophyll a of 17 lakes in Zackenbergdalen July-August 1997 and in the same lakes July-August 2003. Mean values are given with the standard deviation in brackets.

pled on 18 August. In Sommerfuglesø, the species recorded were the cladoceran *Daphnia pulex*, the copepod *Cyclops abyssorum alpinus* as well as the rotifers *Polyarthra dolicopthera* and *Keratella quadrata* (Table 3.45). The fact that *D. pulex* dominated the community probably explains the low abundances of copepods and rotifers. *C. abyssorum alpinus* and *P. dolicopthera* dominated the community in Langemandssø, where arctic charr are present and consume large-bodied zooplankton such as *Daphnia* and adult copepods.

In 1997, a large lake survey was carried out to determine the status of lakes in Morænebakkerne for the purpose of selecting two lakes to be included in the monitoring programme. The results of the survey were presented in Meltofte and Rasch (1998). The lakes were re-visited in 2003 to investigate if changes had occurred in the basic water chemistry. Two of the lakes had dried out (Mellemsø and Trip), and in the remaining 17 lakes significant differences (two-tailed paired t-test; $p<0.01$) were observed in water temperature (increase), pH (decrease), conductivity (decrease) and total phosphorous (increase). Total nitrogen concentrations, in contrast, remained unchanged (Table 3.46). The chlorophyll *a* values also differed significantly between the two years, with a 44% higher concentration in 2003 than in 1997.

Also two other lakes were investigated in 2003: Gåsesø and Lindemannssø. Gåsesø proved to be a nutrient rich lake (*i.e.* high concentration of phosphorous and consequently high chlorophyll *a*), while Lindemannssø featured the same characteristics as the average lakes of the area (*i.e.* nutrient poor and low phytoplankton biomass).

4 Zackenberg Basic: The MarineBasis Programme

Søren Rysgaard, Egon Frandsen, Mikael K. Sejr and Peter B. Christensen

Numerical simulations of future climate performed by use of general circulation models all agree that climate warming will occur first and most intensively in arctic and subarctic regions (*e.g.*, Manabe and Stouffer, 1993; Cattle and Crossley, 1996; Shindell *et al.*, 1999; Flato and Boer, 2001). Surface air temperature observations reveal that the largest increase in recent decades has occurred over Northern Hemisphere land areas from about 40 to 70° N (Serreze *et al.*, 2000). Due to warming of the world oceans (Levitus *et al.*, 2000) the sea-ice cover in the Arctic has decreased by *c.* 14% since the 1970s (Johannessen *et al.*, 1999). This decrease has led to prolongation of the open-water period off the north coast of Russia and in the Greenland Sea, the Barents Sea, and the Sea of Okhotsk (Parkinson, 1992). Higher atmospheric temperatures will increase the transport of water vapor toward the

	7 August			13 August			21 August		
	mean number/m2	SE, n=3	% of total	mean number/m2	SE, n=3	% of total	mean number/m2	SE, n=3	% of total
Copepods									
Pseudocalanus spp.	4202.7	1245.6	14.4	3338.7	896.4	6.3	5376.0	1696.1	16.5
Pseudocalanus spp. *Nauplii*	2058.7	1213.5	7.0	1930.7	725.6	3.7	1141.3	374.2	3.5
Oithona spp.	6304.0	2633.8	21.6	13642.7	4031.3	25.8	8298.7	1975.5	25.5
Oithona spp. *Nauplii*	3904.0	1810.6	13.4	19413.3	5950.9	36.8	3520.0	923.0	10.8
Calanus hyperboreus	3808.0	992.7	13.0	4704.0	1190.6	8.9	6069.3	491.0	18.7
Calanus hyperboreus Nauplii	1669.3	609.7	5.7	2432.0	517.3	4.6	778.7	197.5	2.4
Calanus glacialis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calanus finmarchicus	42.7	42.7	0.1	96.0	55.4	0.2	213.3	76.9	0.7
Onchaea	4944.0	2080.6	16.9	5109.3	1596.4	9.7	5536.0	1347.2	17.0
Microcalanus	1978.7	973.6	6.8	1557.3	232.5	3.0	1301.3	333.2	4.0
Acartia cla.	0.0	0.0	0.0	0.0	0.0	0.0	10.7	10.7	0.0
Harpacticoida	288.0	129.3	1.0	245.3	111.4	0.5	266.7	101.8	0.8
Metridia longa	0.0	0.0	0.0	10.7	10.7	0.0	0.0	0.0	0.0
Cirripedia	21.3	21.3	0.1	298.7	139.9	0.6	21.3	21.3	0.1
Other Groups									
Bivalvia, larvae	74.7	28.2	0.6	13610.7	5118.0	53.2	362.7	267.3	3.1
Gastropoda, larvae	8362.7	2162.6	70.2	3690.7	314.3	14.4	9898.7	2734.7	84.3
Fritellaria, bor.	1301.3	554.7	10.9	384.0	84.7	1.5	778.7	282.8	6.6
Oikopleura	197.3	125.4	1.7	160.0	32.0	0.6	160.0	84.7	1.4
Polychaeta, larvae	517.3	262.6	4.3	64.0	37.0	0.3	117.3	10.7	1.0
Echinodermata, pluteus	42.7	42.7	0.4	0.0	0.0	0.0	64.0	37.0	0.5
Ctenophora, larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda	0.0	0.0	0.0	32.0	32.0	0.1	106.7	56.4	0.9
Chaetognatha	48.0	40.3	0.4	7552.0	1865.2	29.5	42.7	21.3	0.4
Radiolaria	1344.0	815.4	11.3	21.3	21.3	0.1	170.7	170.7	1.5
Isopoda	0.0	0.0	0.0	53.3	38.5	0.2	42.7	42.7	0.4
Hydromedusae	21.3	21.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Limacina helicina	5.3	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.1. Composition of zooplankton in the upper 160 m of Young Sund at three sampling dates in August 2003.

North Pole, resulting in an increase in precipitation and freshwater supply to high latitudes. This prediction agrees well with the observed general increase in precipitation in the 55–85° N latitude band during the last century (Serreze *et al*., 2000).

A regional atmosphere-ocean model for Northeast Greenland predicts a temperature increase of 6-8°C by the end of this century (2071-2100) which will lead to increase in freshwater runoff, thinning of the sea ice, and an increase in the ice-free period from 2.5 months to 4.7–5.3 months in Young Sund (Kiilsholm *et al.* 2003, Rysgaard *et al.* 2003).

The increased freshwater input will greatly enhance the estuarine circulation and nutrient input to the fjord, and is expected to increase biological productivity (Rysgaard *et al.* 2003). The study area around Zackenberg Station is considered to be a sensitive indicator of climate change because of its contact with water masses from the Greenland Sea and direct meltwater flux from the Greenland Ice Sheet. It is believed that the predicted climate changes will dramatically alter conditions in the Greenland Sea as well as coastal hydrological conditions. The long-term marine monitoring program, MarineBasis, which is a supplement to the current monitoring program of the terrestrial environment, is reported in this section.

The MarineBasis program collects data describing physical, chemical and biological components of the Young Sund-Tyrolerfjord system, hereafter referred to as Young Sund. This includes data from sea ice, water column and sea floor. In the sea ice compartment annual measurements of thickness as well as distribution of sea ice and snow in the outer parts of Young Sund are being performed. In the water column compartment, annual measurements of temperature, salinity, tides and vertical export of organic matter (sedimentation) are being made. Furthermore, vertical measurements are made of light (PAR), optical characteristics of dissolved organic matter (DOM), chlorophyll, nutrients, dissolved inorganic carbon (DIC), alkalinity, pH and the composition of the most dominant plankton components during the open-water period. At the sea floor, measurements are made of oxygen, DIC and nutrient exchange rates between the sediment and overlying water. Furthermore, measurements of vertical concentration profiles of oxygen and bacterial sulfate reduction activity are made, along with measurements of permanent accumulation (burial) of material in the sediment. The composition and distribution of benthic animals in the outer parts of Young Sund are being determined along with measurements of the annual growth rates of selected bivalves and macroalgae. Finally, the number of walruses that haul out at the island Sandøen in the outer part of Young Sund is reported.

MarineBasis is conducted by Department of Marine Ecology, National Environmental Research Institute, Denmark. The conceptual design, geographical positions and sampling procedures of the marine monitoring program can be downloaded at www.zackenberg.dk.

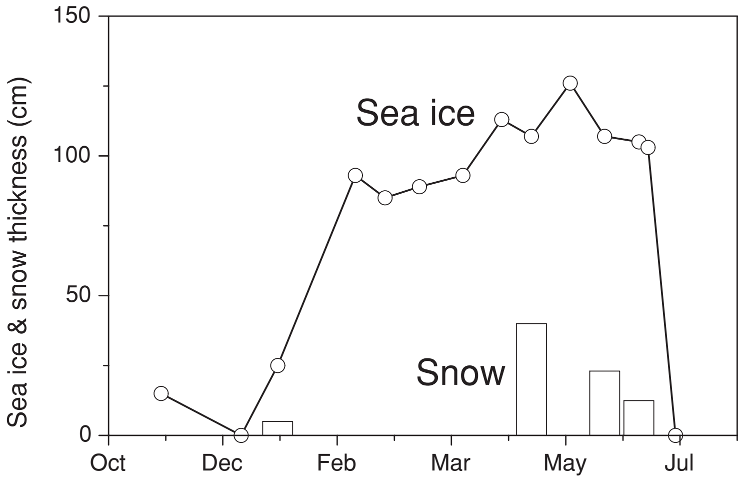


Figure 4.1. Snow and sea ice conditions in Young Sund 2002-03.

4.1. Sea ice

SIRIUS Dogsledge Patrol collected sea ice and snow data for us at 74°18.59’N, 20°15.04’W. Normally, sea ice begins to form in late September to early October and stays until the following summer thaw. However, this year sea ice broke 25 December and was exported to the Greenland Sea due to high wind speeds from the North and lack of sea ice outside Young Sund. Sea ice thickness reached *c.* 120 cm and a maximum of 40 cm snow cover was observed in April-May. Sea ice broke 3 July in outer Young Sund, 3 weeks earlier than normal (Figure 4.1).

Two camera systems were set up to monitor the distribution of sea ice in the outer region of Young Sund. These data will be used to monitor the length of the ice-free period (open-water period) in this

	Water depth (m)	Org C (%)	C/N (atomic ratio)	Porosity (v/v)	Density (g/cm^3)	Stone content (v/v)
74°18,58'N, 20°14,48'W	20	0.5	12.2	0.46	1.69	0.169
74°18,58'N, 20°15,04'W	36	1.4	10.3	0.65	1.44	0.128
74°18,58'N, 20°15,74'W	60	1.1	11.2	0.62	1.52	0.022
74°18,58'N, 20°16,92'W	85	1.1	11.4	0.67	1.45	0.017
74°18,58'N, 20°18,00'W	163	1.2	11.6	0.75	1.36	0.001

Table 4.2. Organic carbon content, C/N ratio, porosity, density and stone content (diam. > 10 mm) in the upper 5 cm of the sediment from Young Sund, August 2003.

	Water depth (m)	>125 µm	63-125 µm	<63 µm
74°18,58'N, 20°14,48'W	20	44.2	24.6	31.2
74°18,58'N, 20°15,04'W	36	10.0	17.0	73.0
74°18,58'N, 20°15,74'W	60	7.7	17.1	75.2
74°18,58'N, 20°16,92'W	85	6.0	4.9	89.1
74°18,58'N, 20°18,00'W	163	13.3	18.8	67.9

Table 4.3. Grain size in the upper 5 cm of the sediment at various depths in Young Sund, August 2003. Values are in % of total.

	O_2	DIC	NO_3-	NH_4^+	PO_4^{3-}	SiO_4
mean	-5.19	6.96	0.220	-0.001	-0.017	0.54
SE	0.52	2.29	0.008	0.061	0.013	0.09
n	10	10	10	10	10	10

Table 4.4. Sediment-water exchange rates of different solutes at 60-m station (74°18.58'N, 20°15.74'W) in Young Sund, August 2003. Negative values represent a flux into the sediment and positive values represent a flux out of the sediment. Rates are in mmol m^{-2} d^{-1}.

region. In 2003, the ice-free period was 140 days. Compared with the average of *c.* 80 days (Based on data from 1950-2003 – Rysgaard *et al. in prep.*), the ice-free period observed this year was exceptionally long.

4.2. Water column

Continuous data on temperature, salinity and water level

A mooring system equipped with conductivity, temperature and pressure sensors and a sediment trap (Figure 4.2) was launched at position 74°18.90'N, 20°16.73'W. The system collects continuous data on temperature, salinity and water level at two water depths together with sedimentation rate measurements at *c.* 66 m. The system is placed below the sill depth of 45 m that is found at the entrance to the fjord, which means that icebergs entering the fjord from the Greenland Sea do not reach deep enough to destroy the mooring system. The upper buoy-system is included for safety reasons only. It will allow us to dive to the mooring system and raise it in case the acoustic release system fails. In addition to the mooring system we launched another mooring equipped with only a salinity, temperature and water level logger system at 25 m water depth at 74°18.86'N, 20°14.78'W to monitor the upper water column with regard to freshwater supply. These data will be available for the 10th Annual Report when the mooring systems are retrieved and data extracted. However, during this year's field campaign we launched a data collecting system for two weeks in order to be able to give an example of the data collection in this year's report (Figure 4.3).

Sediment trap data

This year we retrieved the sediment trap launched in 2002. The trap collected material at a water depth of 60 m at the position 74°18.93'N, 20°16.70'W. Sedimentation was closely linked to the break-up of sea ice and the productivity of phytoplankton (Figure 4.4). Sedimentation was very low during autumn, winter and spring until sea ice break-up when light stimulated phytoplankton production. During this period, sedimentation of up to 80 mmol C m^{-2} d^{-1} occurred. If production had set in earlier in the Greenland Sea due

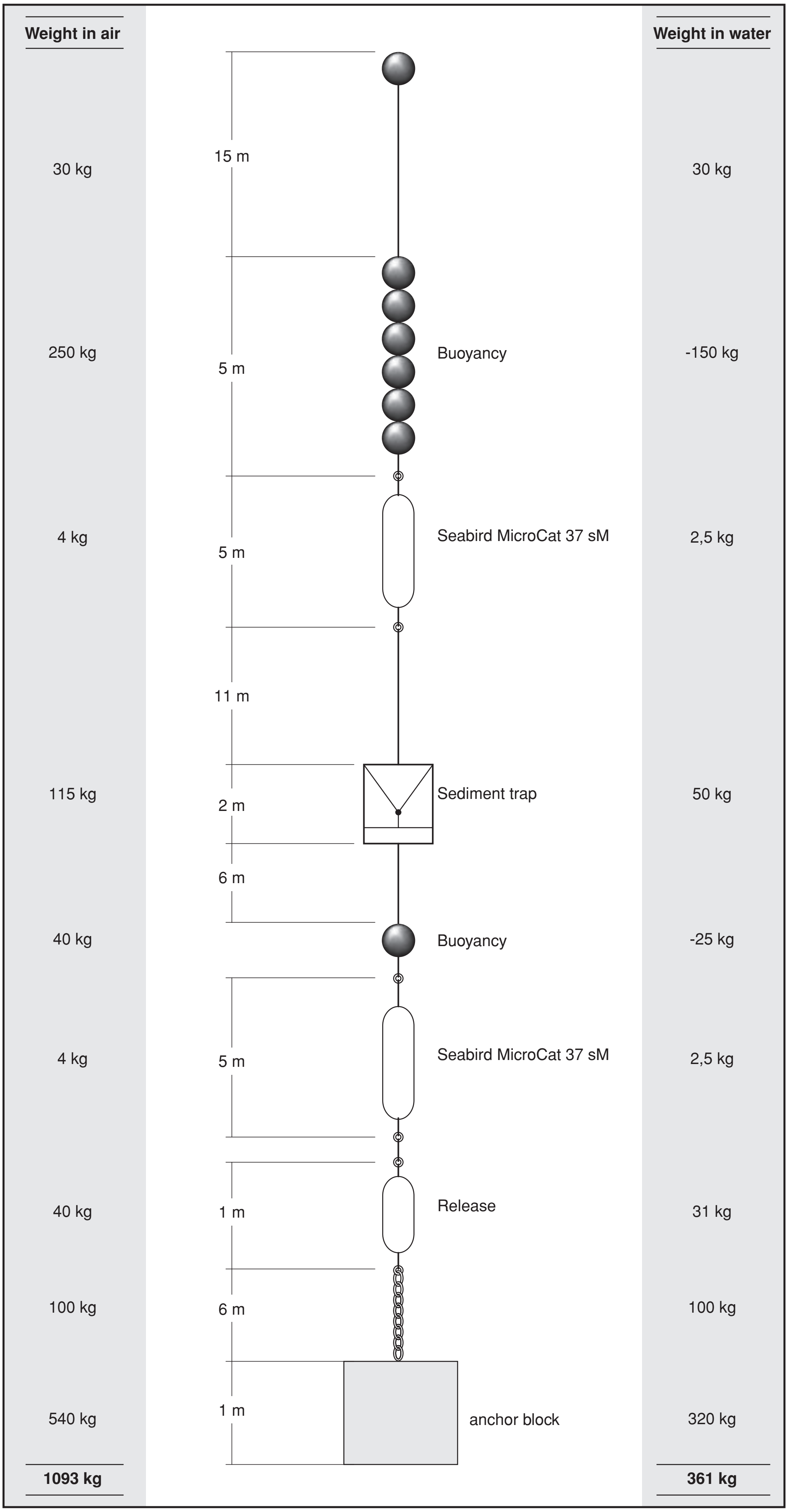


Figure 4.2. Mooring system for measuring temperature, salinity, water level and sedimentation.

to earlier sea ice break-up, phytoplankton would have been imported to Young Sund due to the large exchange of water between the outer area of the fjord and the Greenland Sea (Rysgaard *et al.* 2003). As the sea ice in Young Sund breaks up at the same time as the ice off the coast in the Greenland Sea the measurements in Young Sund represent conditions in the coastal areas of the Greenland Sea. Annual sedimentation for 2002-03 corresponded to 1592 mmol C m^{-2} or 1.6 kg dry weight material m^{-2}. Data on the isotopic signature (^{13}C and ^{15}N) as well as the composition of the material are currently being analyzed and will be presented in next year's report.

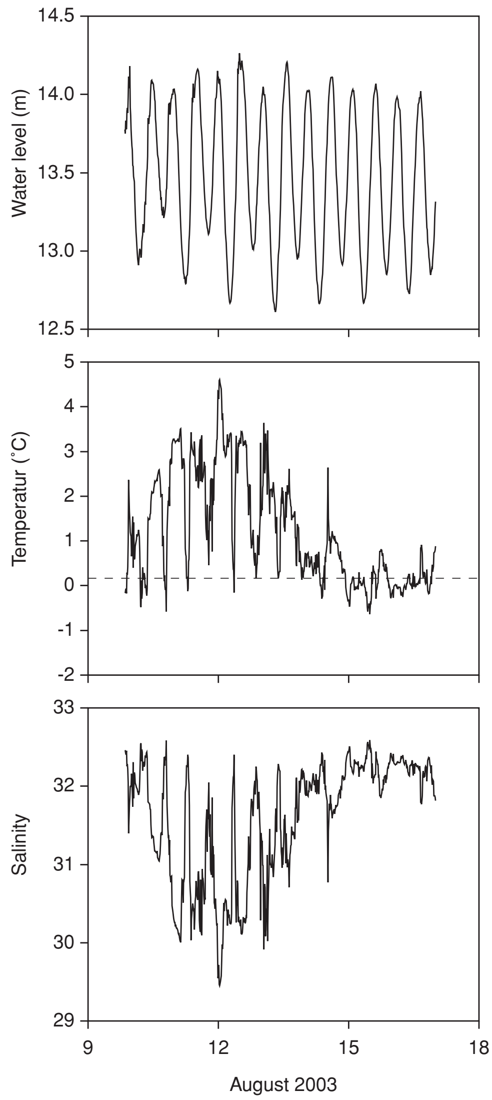


Figure 4.3. Data from the annual hydrographic measurements made by the mooring systems. Example from August 2003.

Vertical profiles of salinity, temperature and Chlorophyll a across and along Young Sund

Young Sund is a deep-sill fjord with significant buoyancy input in the form of freshwater from the melting of snow and ice in the catchment area and the melting of sea ice. During the ice-free period, the freshwater input and mixing by wind and tides results in an estuarine circulation, where lighter water of salinity <30 is moved seaward above denser water from the East Greenland Current with a salinity of 31.5-33.5 (For further details see Rysgaard *et al.* 2003).

Temperature, salinity and Chlorophyll *a* conditions were measured along and across Young Sund (Figure 4.5). In MarineBasis, it is our plan to include measurements from the sill near Sandøen to the Tyrolerfjord but in years with little sea ice (such as in 2002-03) we will extend measurements to include positions outside the sill in the Greenland Sea. This year, the primary pycnocline was found at a depth of *c.* 5 m, and the surface-layer salinity was in the range of 27-29.5. The surface-layer temperature was 3-7°C. A secondary pycnocline was found at *c.* 20 m with salinities of 32 and with temperatures of 0°C at 20 m depth. Salinity reached 33.5 and temperatures dropped <-1.5°C deeper in the water column. Chlorophyll *a* values in the range of 0.25-1.0 μg liter^{-1} were found in the upper 40-50 m. Temperature, salinity and Chlorophyll *a* values indicate that conditions inside and outside Young Sund are similar in the upper 50 m.

The variability of temperature, salinity and Chlorophyll *a* during August at a fixed location (74°18'58''N, 20°18'00''W water depth of 163 m) was investigated by measurements every second day (Figure 4.6). Conditions were fairly stable during august. However, windy conditions

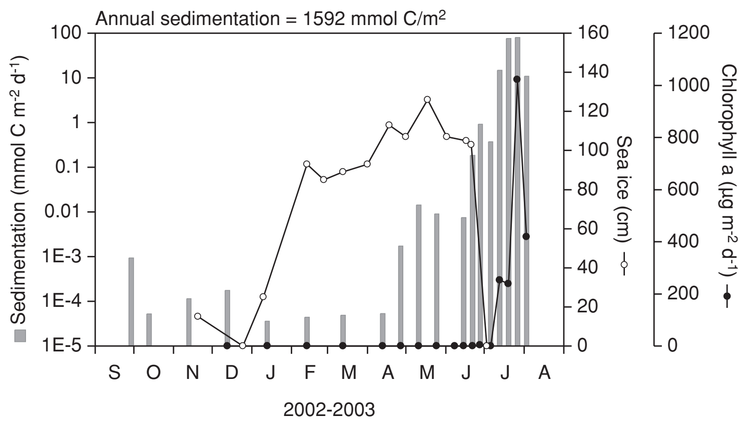


Figure 4.4. Sea ice thickness (-o-), chlorophyll (-?-) and sedimentation (bars) at 60 m water depth in the outer region of Young Sund. Note the log scale for sedimentation rates.

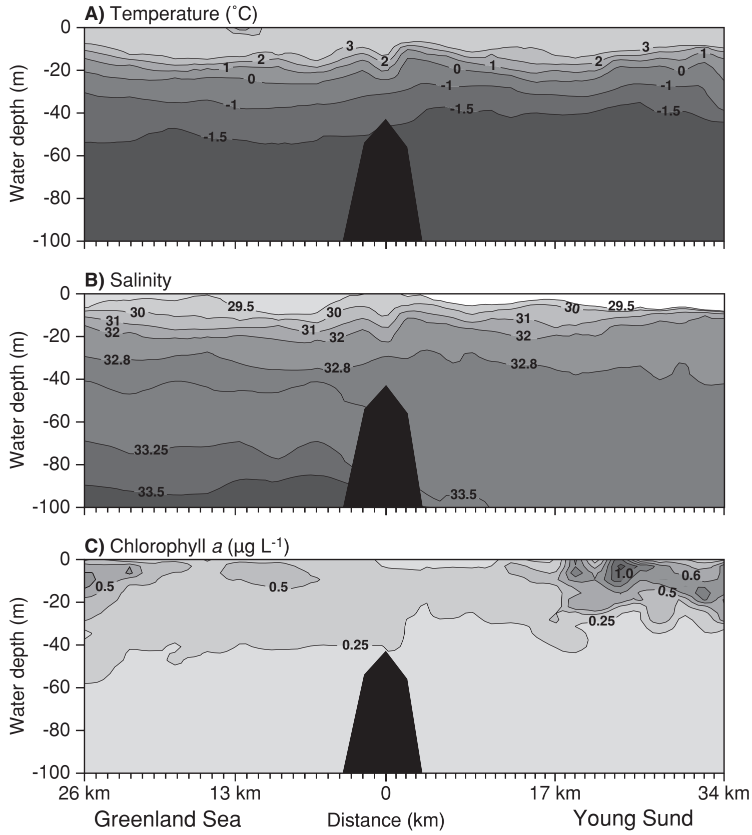


Figure 4.5. Temperature, salinity and chlorophyll a conditions from "Lerbugten" inside Young Sund to c. 30 km off the coast in the Greenland Sea, August 2003. The black area at 0 km is the sill in the outer area of Young Sund.

around 18 August caused mixing in surface waters and an increase in Chlorophyll *a* values in the surface waters in the following days.

Light and optical properties of dissolved organic matter (DOM)

On several occasions we measured the attenuation of light (PAR) in the water column of Young Sund at the location 74°18.58'N, 20°18.00'W, water depth 163 m. Furthermore, we collected water from 1 m, 5 m and 150 m for determination of the optical properties of DOM in the laboratory. Light attenuation coefficients were calculated for PAR based on the vertical PAR profiles (Figure 4.7). The attenuation coefficient varied from 0.09 to 0.14 during August with a mean value of 0.117 ± 0.007 m^{-1} (SE, n=6). In response to the concern raised regarding increased UV levels in the Polar Regions we investigated the absorption characteristics of DOM in the water column of Young Sund during 7, 13 and 21 August (Figure 4.8). The absorption coefficient for DOM of UV-B in the wavelength range of 280-315 nm was 1.27 ± 0.05 m^{-1} for the upper 5 meters and increased with water depth. Thus, <1% of incoming UV-B will reach a depth of 4 m in the water column.

Nutrients, pH, dissolved inorganic carbon (DIC) and total alkalinity (Alkt)

Nutrients, pH, DIC and Alk_t conditions in the water column of the location 74°18.58'N, 20°18.00'W, water depth 163 m, were measured on three occasions (7, 13 and 21 August). The nitrate concentration was very low in surface waters due to phytoplankton uptake and dilution by meltwater, and increased with depth to 4-5 μM (Figure 4.9). Phosphate concentrations were detectable in surface waters and increased to 0.6 μM in bottom waters. Silicate concentrations followed the same vertical concentration profile as nitrate and phosphate except that increased concentrations were observed in the upper 10-m freshwater layer. Ammonium concentrations were below detection level (<0.2 μM) and therefore not shown.

Dissolved inorganic carbon ranged from 1650 μmol kg^{-1} in the upper 10 m of the water column to 2210 μmol kg^{-1} in the bottom water of Young Sund (Figure 4.10). Alk_t followed the same vertical trend as DIC and ranged from 1810 to 2280 μmol kg^{-1} in the water column. Atmospheric pCO_2 levels were significantly higher than pCO_2 levels in the surface waters at all sampling dates showing that the CO_2 flux was directed from the atmosphere into the water column of Young Sund. pH varied from 7.8 to 8.0, peaking in the upper 20-30 m photic zone where increased Chlorophyll *a* levels were found (compare Figures 4.7 and 4.10).

Phytoplankton and zooplankton

On 7, 13 and 21 August, triplicate vertical net hauls from 160 m to the surface at the location 74°18.58'N, 20°18.00'W were performed with a 20-μm net and a modified WP2 (50 μm) net for phytoplankton and zooplankton composition, respectively. Diatoms dominated the phytoplankton community during August, contributing

	mean	SE	min	max	n
Growth of new leaf blades (cm yr-1)	108.6	7.6	47.0	167.0	14
Production of new leaf blades (g C yr-1)	15.1	1.3	8.1	23.8	14

Table 4.5. Annual growth of Laminaria saccharina in Young Sund.

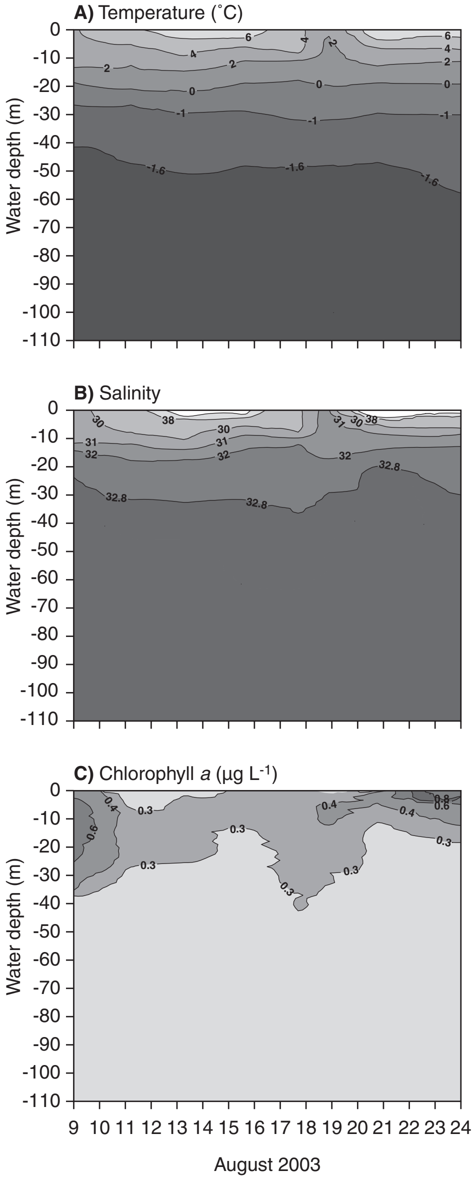


Figure 4.6. Temperature, salinity and chlorophyll a conditions in Young Sund, August 2003.

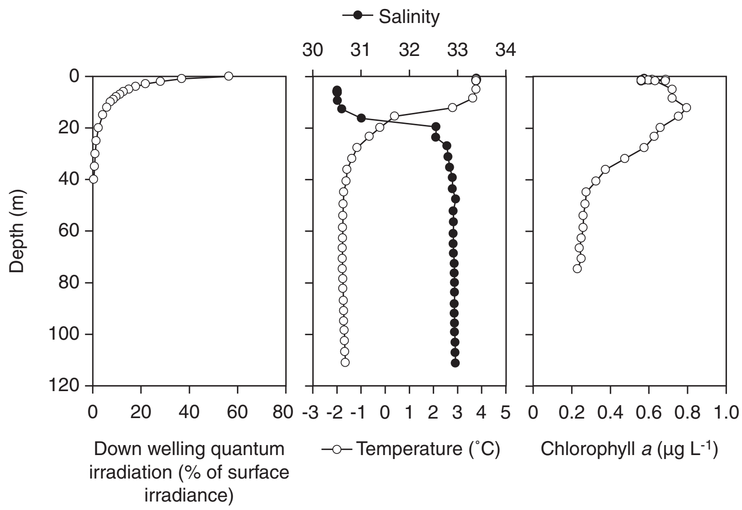


Figure 4.7. Example of light, temperature, salinity and chlorophyll a conditions in Young Sund on 9 August 2003.

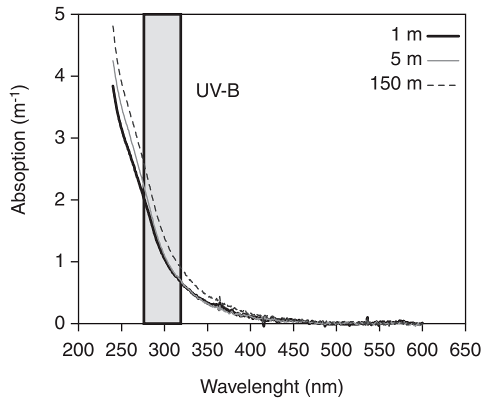


Figure 4.8. An example of the absorption characteristics of dissolved organic matter in the water column of Young Sund on 7 August 2003.

62-74% of the total pelagic phytoplankton assemblage. Centric diatoms accounted for 54-58% of which *Chaetoceros* species were the most abundant. Other centric diatoms such as *Coscinodiscos*, *Synedra* and *Melosira* were also present. The pennate diatoms (8-16% of total assemblage) were dominated by *Naviculales* and *Nitzschia,* but also *Licmophora*, *Achnanthes* and *Gyrosigma* were present. Dinoflagellates such as *Protoperidinium*, *Dinophysis* and *Ceratium* accounted for 26 to 31 % of the phytoplankton assemblage. Finally, *Dictyocha* belonging to Dictyocophyceae accounted for a few percent of the total phytoplankton assemblage.

Copepods dominated the mesozooplankton. The late summer mesozooplankton community was composed of *Calanus spp*., *Pseudocalanus spp*., *Microcalanus spp*., *Oithona spp*., *Onchaea spp*., and some harpacticoid copepods and *Cirripedia* (Table 1). Additionally, larvae from benthic invertebrates, Bivalvia, Gastropoda, and Polychaeta, were identified as well as appendicularians, represented by *Fritillaria* and *Oikopleura spp*. Among the copepods, *Oithona spp.* was the most abundant group followed by *Calanus hyperborius*, *Pseudocalanus spp*. and *Onchaea*. *Calanus glacialis* have earlier been found in large numbers in Young Sund (Rysgaard *et al.* 1999) but had apparently already migrated to deeper waters and were therefore not seen during this sampling campaign. The ratio between two of the dominating Calanus species, the "warm-water" *Calanus finmarchicus* and "arctic-water" *Calanus hyberboreus*, can be used as an indication of changing circulation patterns in the Greenland Sea.

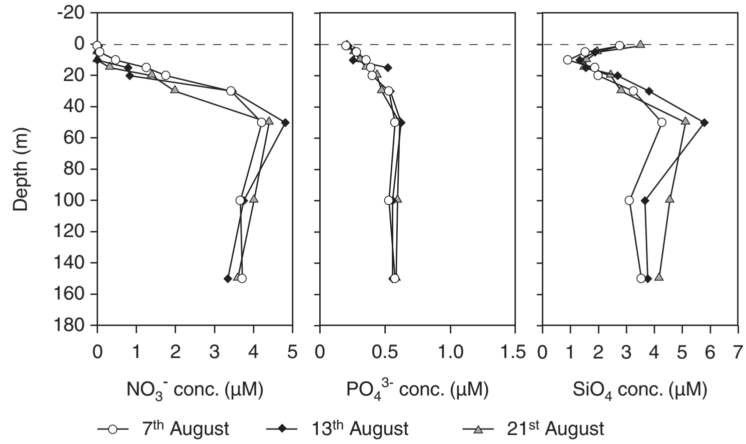


Figure 4.9. Nitrate, phosphate and silicate in the water column of Young Sund, August 2003. Ammonium concentrations were below detection level (<0.2 µM).

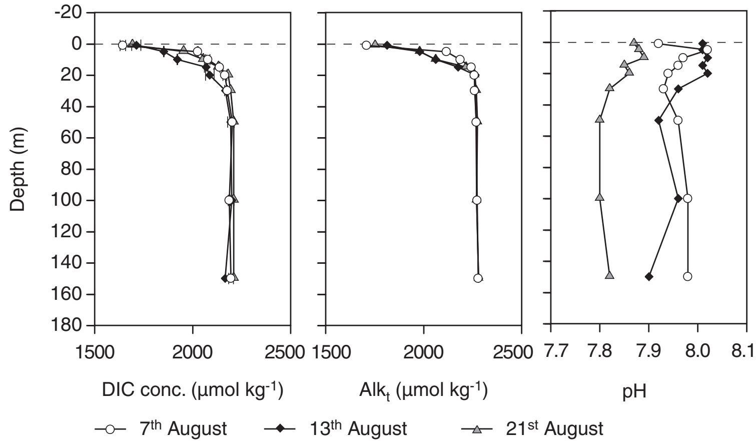


Figure 4.10. Discovered inorganic carbon, alkalinity and pH conditions in the water column of Young Sund, August 2003.

4.3. Sediment

Sediment characteristics, exchange rates, oxygen conditions, sulfate reduction, nutrients and burial

The organic carbon content, C/N ratio, porosity, density and stone content of the upper 5 cm of the sediment are presented in Table 2. Furthermore, grain size in the upper 5 cm of the sediment of the same localities is given in Table 3. A station at 60 m water depth (74°18.58′N, 20°15.74′W) was chosen as a standard station because it is situated and receives material from below the photic zone and because the sediment does not contain a large amount of stones which would otherwise cause problems with both sampling and electrode measurements.

Material sedimenting from the water column (see Figure 4.4) eventually reaches the sea bottom and becomes available to benthic animals, meiofauna and bacteria. The net exchange of a given solute between the sediment and the water column describes whether it is taken up or released from the sediment. As earlier studies in Young Sund have shown, an increase in the flux of DIC and nutrients out of the sediment is observed as a result of sedimentation of organic matter following sea ice break-up (Rysgaard *et al.* 1998). In an attempt to link this response in the sediment to different sea ice conditions and, hence, productivity conditions during various years, net exchange measurements were performed at the end of August (Table 4). Of the organic matter reaching the sediment through sedimentation, 6.9 mmol C m^{-2} d^{-1} was degraded in the sediment and returned to the overlying water. At the same time, the total oxygen uptake (TOU) rate of the sediment was 5.2 mmol C m^{-2} d^{-1}. Nitrate and silicate were released from the sediment, whereas no significant changes in ammonium and phosphate fluxes were observed.

The vertical O_2 concentration profile in the sediment can be used to describe how O_2 consumption is distributed in the sediment as well as to give indications of the activity of benthic invertebrates and meiofauna. Oxygen penetrated 1.7 cm into the sediment at this 60-m location and the highest O_2 consumption occurred on the sediment surface, indicating recent addition of organic matter to the sediment through sedimentation (Figure 4.11). With time we hope to establish a relation between sea ice conditions, productivity and grazing in the water column, vertical flux (sedimentation) and benthic activity. Such relations have not yet been established in natural systems.

The degradation of organic matter in sediments occurs both aerobically (by use of oxygen) and anaerobically (by use of other electron acceptors, such as nitrate manganese, iron or sulfate). If sea ice conditions change during this century as predicted, it will affect the input of organic matter to the sediment and thus the balance between aerobic and anaerobic degradation. As sulfate reduction (SRR) accounts for a substantial fraction of the anaerobic degradation in Young Sund (Rysgaard *et al.* 1998) we included these measurements at the 60-m locality. The integrated sulfate reduction rate was 0.43 ± 0.08 mmol m^{-2} d^{-1} (Figure 4.12), which cor-

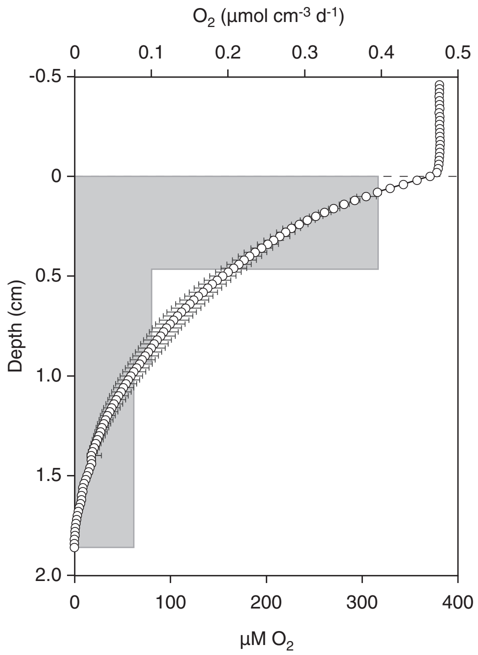


Figure 4.11. Vertical concentration profile of oxygen (dots) and modeled consumption rates (bars) in the sediment at 60 m water depth in outer Young Sund, August 2003. Error bars represent standard error of the mean, n=10.

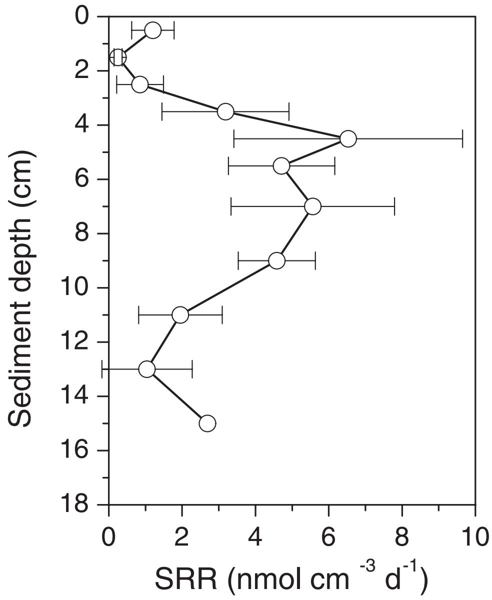


Figure 4.12. Sulfate reduction rates in the sediment at 60 m water depth in outer Young Sund, August 2003.

responds to an organic matter degradation rate of 0.86 ± 0.16 mmol C m^{-2} d^{-1} or *c.* 30% of the diffusive O_2 uptake of the sediment. The material reaching the sediment that is not degraded and returned to the overlying water column is buried (permanently accumulated). This fraction was estimated by analysis of ^{210}Pb and ^{137}Cs in the sediment (Figure 4.13). As the ^{210}Pb (excess) activity in the upper 6 cm of the sediment is more or less constant and thus indicates bioturbation in these layers, we can not calculate the burial rate from either ^{210}Pb or ^{137}Cs profiles. However, the ^{137}Cs content shows a broad peak between 1 and 5 cm depth. This peak is presumably due to the major fallout from atmospheric nuclear tests around 1963 when these activities peaked. As the peak in the sediment is not well defined, the uncertainty in the burial rate based on the period since 1963 is quite high, but the rate is within the interval 0.4-1.1 mm yr^{-1} (0.3-0.8 kg m^{-2} yr^{-1}) which is comparable to burial rates estimated earlier at another locality (36 m water depth) in Young Sund (Rysgaard *et al.* 1998).

Benthic animals

Abundance and composition of macrobenthos are often used as key parameters in the monitoring of marine environments. The dominance of sessile and long-lived animals is ideal, and changes in community patterns can result from processes in both the pelagic and benthic environments. At three different transects in the outer parts of Young Sund we took a series of high-resolution photographs to describe the abundance of key species from 20 to 60 m depth. In total, 15 different species were identified from the photographs. The abundance of dominant species is shown in Figure 4.14. Brittle stars were by far the most abundant group, with a maximum density of close to 400 individuals per m^2. Generally, large differences were observed in density between transects with no apparent pattern, whereas the influence of depth was more predictable. The abundance and composition of benthos changes significantly in Young Sund at a scale of tens of meters (Sejr *et al.* 2000) most likely due to changes in sediment

Figure 4.13. Depth distribution of excess 210Pb and of 137Cs in the sediment at 60 m water depth in outer Young Sund, August 2003.

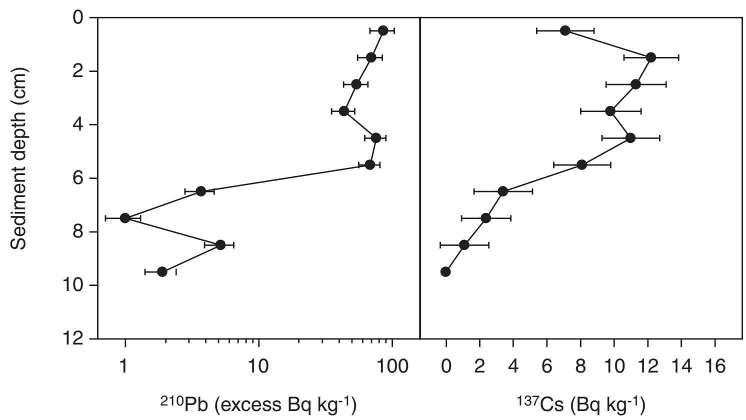
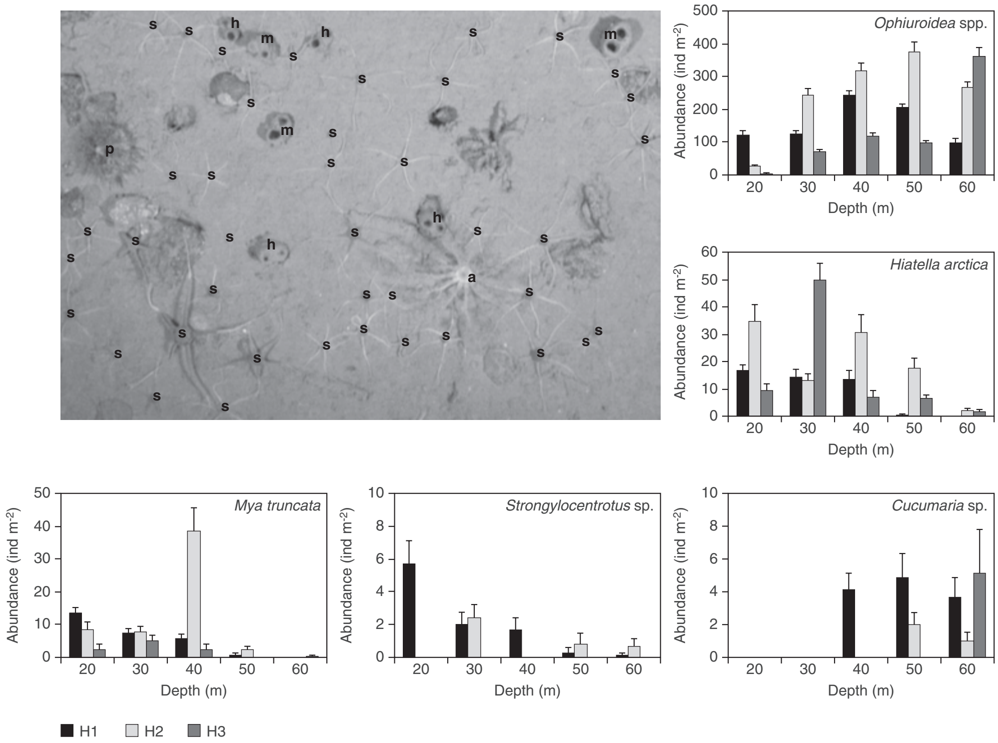


Figure 4.14. Abundance of dominating benthic invertebrates in the outer parts of Young Sund, August 2003. Symbols: m = *Mya*, h = *Hiatella*, a = *Cucumaria* sp., p = *Strongylocentrotus* sp., s = *Ophiuroidea* spp.



Transect	Depths	Photos available	Photo analyzed	Area covered
H1	20 – 60 m	100+	50	18,45 m^2
H2	20 – 60 m	100+	50	13,60 m^2
H3	20 – 60 m	100+	50	11,88 m^2

composition. This was also observed in the photos. To compensate for the large variation in the data, additional photos were taken. These photos were not analyzed but are available if changes are observed that require the inclusion of additional material. The analysis of the annual growth rate of the bivalve *Mya truncata* has been initiated. Specimens were collected and prepared for analysis of internal growth rings. These data will be presented in the 10th Annual Report.

Underwater plants

Earlier leaf-marking studies in Young Sund have shown that annual elongation rates of leaf blades can be obtained in *Laminaria saccharina* because the new blades are easily distinguishable (Borum *et al.* 2002). Thus, it is possible to obtain the annual growth rate of this underwater plant and with time couple it to the productive ice-free period. Table 5 shows that the growth of new leaf blades was 108.6 ± 7.6 cm corresponding to 15.1 ± 1.3 g C yr^{-1} during the 140 ice-free days in 2003.

4.4. Other activities

Walrus, seal and arctic char

MarineBasis will report on the number of walruses at the haul-out location at Sandøen. This year a research project on walruses was carried out by Erik Born *et al.* (see section 5.9). In short, however, a relatively large group of walruses (up to 37 individual) was seen at Sandøen this year.

MarineBasis will also collect material from ringed seal and arctic char in connection with the catch made by The Sirius Dogsledge Patrol. The material will be frozen and may be used in the future as a data bank of contaminants etc.

5 Research projects

5.1. Effects of UV-B radiation on vegetation in Zackenberg

Helge Ro-Poulsen, Teis N. Mikkelsen, Linda Bredahl, Kristian Albert, Kirsten B. Håkansson and Riikka Rinnan

This three year project is intended to end up with a recommendation of a method for long term monitoring of the impact of UV-radiation on the vegetation in Zackenberg. The efforts have been focused on identifying and quantifying the effects of the occurring UV-B irradiance on the physiological performance of the abundant occurring high arctic plant species *Salix arctica* and *Vaccinium uliginosum*. This is done by measurements of the effects of reducing the UV-B irradiance by means of filters mounted above the vegetation cover; cf. the last two annual reports.

During the third growing season four types of treatments were applied to the permanent 47x60 cm plots established in 2001 on two sites with different slopes SE of the station, dominated by *Salix arctica*, *Vaccinium uliginosum*, *Cassiope* and *Dryas*. The treatments were: UV-A and UV-B absorption (transparent Lexan®), UV-B absorption (transparent Mylar® type D), no UV absorption (transparent Teflon®, control) and no filter (filter control), replicated four times at each slope. In 2003 the treatments were initiated in late June and terminated in the middle of August. The measurements concentrated on chlorophyll fluorescence induction kinetics, yielding informations on the functioning of the light energy harvesting parts of the photosynthetic machinery, but also specific leaf area (SLA), relative content of flavonoids (UV-B absorbing pigments) and chlorophyll and species composition have been determined. Within the sites, air and soil temperatures, soil water content, photosynthetic active radiation (PAR), UV-B irradiance and relative humidity were measured. Further, in the end of the season soil samples were collected to investigate possible effects on below ground root and microbial biomass and nutrient allocation. The results from all these measurements are not yet fully analysed.

From the earlier years chlorophyll fluorescence measurements it could be seen that the reduction of UV-radiation caused a significant increase in the parameter F_v/F_m, indicating a lower stress level. However, a large variation in the measurements was observed. To optimise and homogenize the radiation load to the plant leaves, an additional *maximum irradiance experiment* was set up in 2002, in which *Salix* leaves were fixed perpendicular to the solar zenith angle, covered with Mylar or Teflon. The results showed pronounced effects of UV-B reduction on certain chlorophyll fluorescence parameters as well as on the flavonoid content of the leaves. The experiment was repeated in 2003 where much effort was invested in also measuring net photosynthesis and respiration of the leaves. The results still await final data treatment.

In 2002 an experiment was conducted, where net canopy CO_2 exchange was measured on 20 cm diameter *Vaccinium uliginosum* plots covered with Mylar or Teflon.

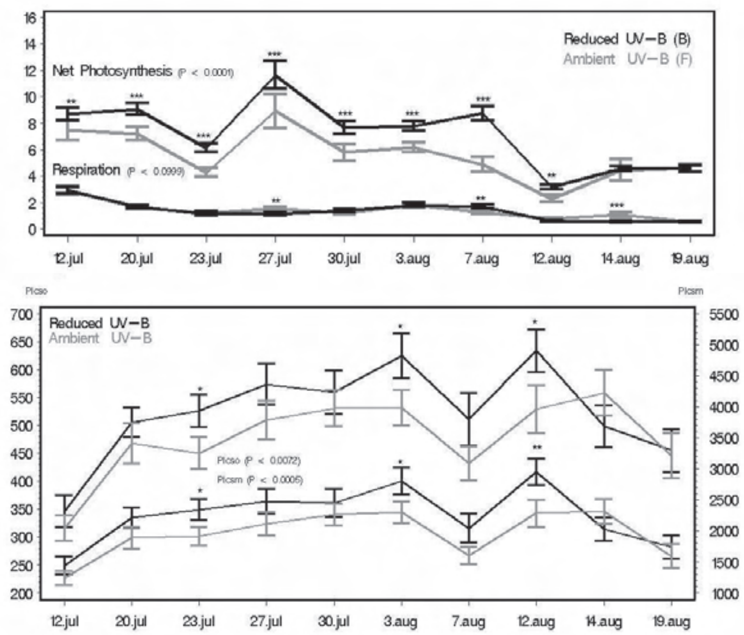


Figure 5.1. Performance of the photosynthetic machinery in a Vaccinium uliginosum plant cover exposed to two UV-B irradiance levels in Zackenberg 2002. Upper graph: Net photosynthesis and respiration. Lower graph: Performance indexes calculated from chlorophyll fluorescence measurements.

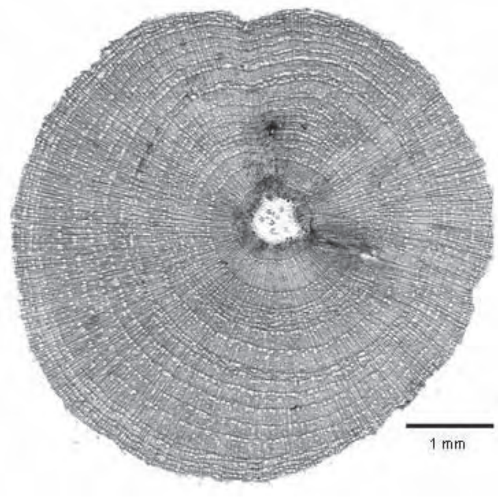


Figure 5.2. Example of a digitized micro-section of an Arctic willow (Salix arctica) *stem collected in Zackenbergdalen, 2001 (from Baittinger 2003).*

Some of the results are shown in Figure 5.1. The ca. 60 % reduction of the ambient UV-B irradiance caused by the Mylar film resulted in a significantly higher net photosynthesis during summer. This is accompanied by significantly higher "performance indexes" obtained by means of chlorophyll fluorescence measurements, proving that the fast and easy chlorophyll fluorescence measurements can give relevant informations concerning the primary productivity.

5.2. Arctic charr population dynamics at Zackenberg

Kjell J. Nilssen and Odd A. Gulseth

Size has a predominant influence on an animal's energetic requirements, its potential for resource exploitation, and its susceptibility to predation. Studies of arctic charr (*Salvelinus alpinus*) at Svalbard indicate that sexual maturity and the timing of habitat shifts (anadromy) may be determined by early metabolic rates and growth rates of the fish. Because fast-growers have a higher metabolic rate than slow-growers of the same size, fast-growing charr has been shown to summer-migrate to sea, which is a more profitable habitat in terms of energy. The studies within the Svalbard archipelago have also revealed that very young, small charr may exhibit a strategy of migrational activity to improve the availability of energy sources and their growth rate.

We have recently undertaken work to compare the growth and mobility of the Svalbard charr with that of the charr residing within Northeast Greenland. During our stay at Zackenberg in July 2003 we therefore collected parr at different locations, *i.e.* the littoral zone at Store Sø and upper, middle and lower part of the river (by use of electric fishing gear).

Although all data have not yet been processed, preliminary results demonstrate improved parr growth when summer feeding in the river. Consequently, it may be this migrating parr which later smoltifies and develops into the anadromous part of the Zackenberg charr population.

In the seasons to come, we hope to estimate the migrating parr population, and to capture and tag all anadromous charrs migrating upstreams after their summer seawater stay. This will reveal the biographics of the anadromous charr population, and may later be used to investigate possible changes related to water temperature changes.

5.3. Temporal and spatial variation in arctic willow radial growth

Niels M. Schmidt and Mads C. Forchhammer

Dendrochronological analysis of radial growth in various tree species is a common tool to reconstruct past climatic conditions, and is referred to as dendroclimatology. In 2001 (Caning and Rasch 2003) and again in 2003 we collected stem samples of arctic willows *Salix arctica* in order to investigate the temporal and spatial variation in annual tree-ring width.

The 49 stem samples collected in 2001 have now been thoroughly analyzed. From each stem, one to three 20 μm sections were made and digitized (Figure 5.2), and radial growth was measured on two to seven radii per micro-section.

Though the radial growth of some individuals can be followed back to the beginning of the last century, most stem samples covered annual growth over the past 40-50 years. Annual growth was very small with an average tree-ring width of 0.12 mm. An example of the year-to-year variation in tree-ring width is shown in Figure 5.3. On the basis of the 49 stem samples, a common dendrochronology for the arctic willow growth in the Zackenberg valley is being constructed.

All samples exhibited a relatively large variation in inter-annual radial growth. Additionally, we also found a relatively large variation in tree-ring width among individuals. This variation may be attributed to gender or habitat specific patterns of growth. Hence, in 2003 we collected 37 male and 37 female arctic willow stem samples from three distinct habitat types (*Salix* snowbed, *Cassiope* heath, and abbreassion plateau; see Bay 1998). These habitat types also represent three levels of exposure to snow. Snow accumulates in the *Salix* snowbed and the snow-free period here is very short. The *Cassiope* heath has intermediary snow depths, while on the abbreassion plateau the snow cover is very thin, and the plateau is therefore one of the first snow-free areas in the valley.

We also tried to collect stem samples in the fen areas. However, they grow beneath a thick layer of mosses and have a large number of roots emerging from the stems. Hence, they are not suitable for dendrochronological analysis. The annual radial growth will be contrasted and compared in a spatio-temporal setup among individuals, gender, and habitats and in relation to various climatic variables.

In 2003, we also collected male and female arctic willow stems around a *Salix* monitoring plot (Salix 4; see Meltofte and Berg 2003). The radial growth of these individuals will, together with the BioBasis data on arctic willow reproduction, allow the analysis of the possible trade-off between growth and investment in reproduction.

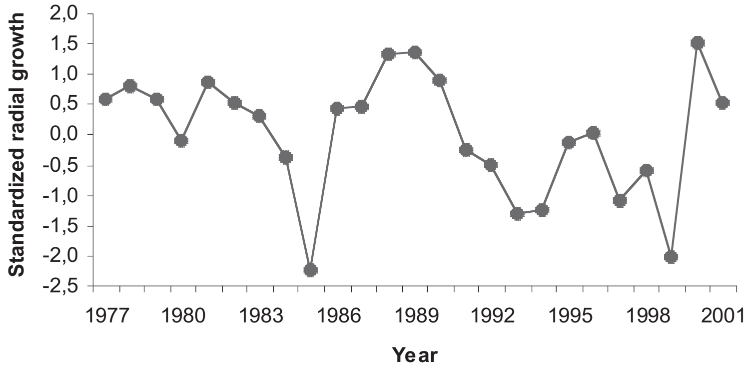


Figure 5.3. Example of the standardized log-transformed annual radial growth in an Arctic willow (Salix arctica) *stem collected in Zackenbergdalen, 2001.*

5.4. The occurrence of insect-pathogenic fungi in soil and flies

Jørgen Eilenberg, Niels M. Schmidt and Christina Wolsted

Insect-pathogenic fungi are commonly found among insects in temperate and tropical regions in the world. However, little is known about their occurrence in the Arctic. In an earlier study, we documented by insect sampling that the fungus, *Strongwellsea* sp.nov, naturally infected Muscoid flies at Zackenberg (Meltofte and Rasch 1998). Another approach is to document the presence of insect pathogenic fungi by investigations of soil samples by the 'insect bait method' using lepidopteran larvae (*Galleria mellonella*) or coleopteran larvae (*Tenebrio molitor*) (Zimmermann 1998). The presence of insect-pathogenic fungi is documented by subjecting the larvae to fungal spores present in the soil. The larvae penetrate the soil to get to the surface. Every day the cups with soil samples are turned, and, hence, the larvae must penetrate the soil once again, thereby increasing the likelihood of getting infected by spores present in the soil.

In 2003, 20 soil samples were collected in the Zackenberg valley in order to determine the fungi species present. Samples were taken in various habitat types (*i.e. Dryas* heath, *Salix* snowbed, *Cassiope* heath and *Vaccinium* heath). Bait larvae were transferred in the bottom of plastic cups, and added 150 ml soil. Dead larvae were regularly removed and incubated in moist chambers, which allowed fungal infections to develop and show the typical symptoms. Hereafter diagnosis was possible. Figures 5.4 and 5.5 show examples of fungus-killed bait insect larvae.

In the soil samples the presence of two insect pathogenic fungi was documented. In five samples *Paecilomyces farinosus* was found, and *Paecilomyces fumoso-roseus* was found in one sample. Both species are commonly found in Denmark, but have to our knowledge not been found in the Arctic before.

In 2003, we also sampled flies to get additional information about the insect-pathogenic fungi. We found several fly specimens killed by the fungus *Entomophthora muscae* s.l. Diagnosis to the species-level of this fungus is currently being done on the basis of conidia morphology. However, despite a specific search we did not obtain a single specimen with infections by *Strongwellsea* sp.nov., though the fungus has previously been found in dipterans from Zackenberg (Meltofte and Rasch 1998).

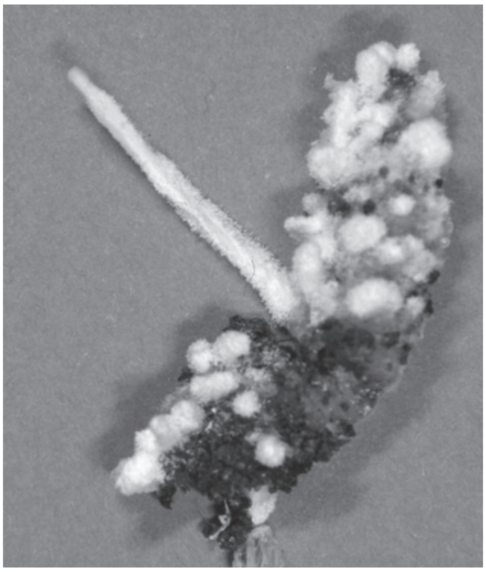


Figure 5.4. Larva of Galleria mellonella killed by the fungus Paecilomyces farinosus

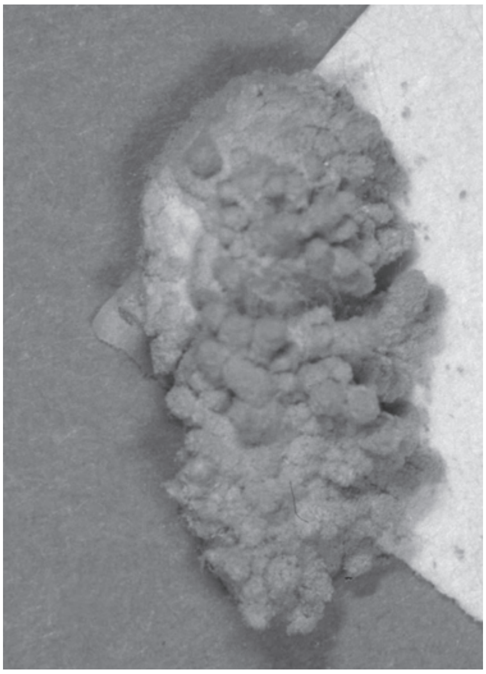


Figure 5.5. Larva of Galleria mellonella killed by the fungus Paecilomyces fumoso-roseus

5.5. Microbiological studies in hot springs at Daneborg and Scoresbysund

Michael Kühl, Ronnie Glud, Søren Rysgaard and Hans Pedersen

Hot springs with constant source water temperatures ranging from just above zero to >60ºC can be found all over Greenland. In the area around Disko, West Greenland, about 10,000 warm springs are estimated to exist. The most famous spring is found at Unartoq at the southern tip of Greenland where the springing water is *c.* 42ºC. This spring has been known since the first Norse settlements.

The hottest springs are found in East Greenland at a number of locations north and south of Scorebysund. The source water temperatures reach above 55-60ºC and thus potentially sustain true thermophiles. Some of these springs have been known since the early explorers, and the presence of colored, slimy coatings in the spring water was mentioned in several expeditions' journals. Hitherto most research has focused on the very special flora and fauna thriving in the mild microclimate surrounding many springs, while the microbiology of the Greenland hot springs remains largely unexplored.

In July 2003 an expedition, financed by the Carlsberg foundation and the Danish Natural Science Research Council, was carried out by the authors to perform the first microbiological field studies in hot springs at three localities (Kap Tobin, Nørrefjord, and Rømer Fjord). We found over 70 sources with water temperatures of >40ºC. In August 2003, we also found a spring at Daneborg (5-6ºC). Here we briefly describe the characteristics of microbial mats in the Daneborg spring and compare them with mats found in the Kap Tobin spring.

In all springs, irrespective of pronounced differences in water chemistry and temperature, we found characteristic orange, green and brownish colored slimy coatings covering the sides and the bottom of the springs (Figures 5.6 and 5.7). The coatings were mainly composed of a dense network of filamentous cyanobacteria (Figure 5.6, C-E) embedded in a matrix of exopolymers forming up to 10 cm thick gelatinous microbial mats (Figures 5.6, B, and 5.7, A). The cyanobacteria were of different morphotypes, but most belonged to the *Oscillatoria* group. In the Daneborg spring also some diatoms and few filamentous green algae were present in the slimy matrix, but oscillatorian cyanobacteria were the predominating mat builders.

While the Daneborg spring exhibited thick microbial mats in water of 5-6ºC, such microbial mats were only found in water of >40ºC in the other field localities. Below this temperature flies, insect larvae and other grazers destroyed the mat fabric. Especially, dense patches of the ephidryd flies (tentatively identified as *Scatella thermarum*), were found grazing on the mats at around 40ºC. The flies were preyed upon by hunting spiders (tentatively identified as *Pirata piraticus*), which

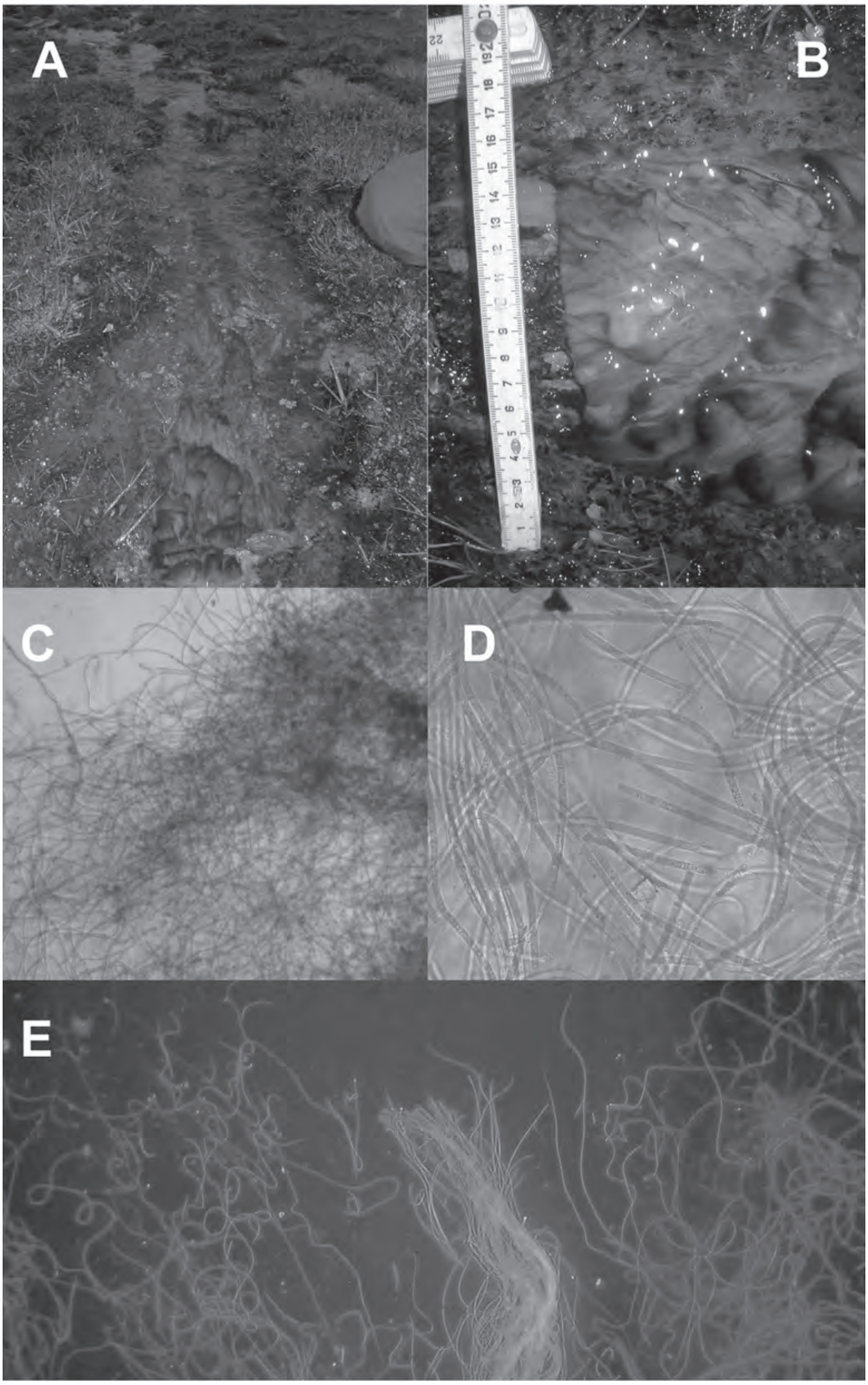


Figure 5.6. Thick microbial mat found in a 5-6°C warm spring close to Daneborg in Northeast Greenland in August 2003 (A, B). The mat consisted of a cohesive slimy matrix of exopolymers embedding a dense network of filamentous cyanobacteria (C, D). Besides chlorophyll a, the cyanobacteria contained large amounts of water soluble phycobiliproteins, showing red fluorescence when the filaments were excited with orange light (E).

went on fast forays across the hot water to reach patches with flies. Why the mats in the Daneborg spring were not subject to similar grazing pressure is presently unknown and needs further investigation.

The temperature in the Daneborg spring was about 10 times lower than in the other hot springs investigated. Consequently, different microbial communities are probably present in the mats from these two temperature habitats. Nevertheless, the mat structure and mechanical properties were very similar. The cyanobacteria in all microbial mats exhibited spectral signatures showing the presence of high levels of chlorophyll and phycobiliprotein pigments, the latter of which caused an intense red fluorescence from filaments excited with orange light (Figure 5.6, E). The high transparency of the microbial mats allowed for a thick zone of photosynthetic oxygen production leading to super-saturation of the mat with respect to oxygen, as measured *in situ* with oxygen microsensors (Figure 5.7, B). *In situ* microsensor measurements during nighttime showed a gradual depletion of oxygen in the uppermost parts of the mat to levels lower than in the overlaying water. However, deeper layers of the microbial mats showed less consumption and we found no sign of complete oxygen depletion during a full diel cycle.

In situ measurements of the total oxygen exchange between microbial mats and the overlaying water during a diel cycle showed a net production of oxygen during most times. Only during periods of low irradiance, caused by shadows cast from the surrounding landscape at low sun angle, did we measure a net uptake of oxygen by the microbial mat. Integrated over the full diel cycle, however, the mat was apparently producing more oxygen than was consumed. Consequently, the mat acted as a sponge for oxygen causing the prevalence of oxic conditions and sometimes oxygen bubbles within the mat fabric.

The massive amounts of exopolymers, which seem to be characteristic of the Greenland hot spring mats, may also serve as an energy source during the Arctic winter. During this period light is absent leaving the microbial phototrophs to respiratory metabolism, which could largely be using the exopolymers as a substrate. However, a confirmation of the proposed role of the exopolymers awaits further studies, including sampling and *in situ* process measurements in Greenland hot springs during the Arctic winter.

5.6. Soil fauna and soil respiration at Zackenberg

Louise I. Sørensen, Martin Holmstrup and Søren Christensen

Due to harsh climatic conditions the terrestrial invertebrate communities are often not very diverse in Polar Regions. Soil inhabiting macro invertebrates such as earthworms are not present in these areas and the meso and micro fauna are therefore of higher importance for soil processes here than in temperate regions. Moreover, certain species can appear in high numbers.

In order to quantify the soil inhabiting invertebrates and soil respiration, soil samples were collected between July 31 and August 2, near arthropod plots 3, 4, and 5 at Zackenberg (see http://biobasis.dmu.dk). Nine replicates were taken in an area of 10 by 10 m adjacent to the arthropod plots.

The intact soil cores were extracted for soil fauna and analysed at the Danish National Environmental Institute (NERI), Silkeborg, Denmark, and at the University of Copenhagen.

Microarthropods and enchytraeids were extracted at NERI, Silkeborg. The mean density of Collembola was between 32,887 and 138,867 individuals per m^2 distributed on 19 different species. The highest density was found in plot 5. The average density of mites was between 42,434 and 48,742 individuals per m^2 with the highest number in plot 5. The same tendency could be seen for the enchytraeids (plot 5: 3,700 individuals/m^2; plot 3: 336 individuals/m^2). Protozoa and nematodes were extracted and counted at the University of Copenhagen. The density of nematodes was highest in plot 5 (250 individuals/g dry soil) and lowest in plot 4 (65 individuals/g dry soil). The lowest density of protozoa was, contrary to mesofauna densities, found in plot 5 (7,008 individuals/g) and the highest in plot 3 (10,930 individuals/g dry soil).

The microbial biomass was measured using Substrate Induced Respiration (SIR) at University of Copenhagen. There was no difference between the three plots. In all three plots the microbial growth was limited by phosphorus. Only in plot 5 was the microbial growth constrained by the availability of nitrogen.

The content of soil organic matter was measured by loss of ignition at NERI, Silkeborg. The average content of organic matter in the soil layer was between 12.1% and 19.2% with the highest content in plot 3. pH in soil water was also measured at NERI, Silkeborg and was on average highest in plot 5 (between 5.08 and 6.65) and lowest in plot 3 (pH between 4.72 and 5.07).

The highest activity was found in plot five where the density of microarthropods, enchytraeids and nematodes was the highest. Furthermore, the amount of organic matter in this plot was the lowest and only in this plot was the microbial respiration limited by the availability of nitrogen (N).

5.7. Feeding strategy and searching behaviour of the arctic fox *(Alopex lagopus)*

Line A. Kyhn and Thomas B. Berg

Since 1995 the arctic fox has been monitored in the valley Zackenbergdalen as part of the BioBasis monitoring programme. Twelve dens have been found. Surveillance of the dens is part of the monitoring programme and each den is inspected on a weekly to monthly basis in order to determine den activity and breeding status of resident foxes by means of number of pups. Further the BioBasis programme registers all observed foxes in the valley over the season. Total number of observations has been used to estimate the number of local foxes during summer.

Living conditions change profoundly between summer and winter for resident animals in high arctic Greenland. In winter fox diet is limited to ptarmigans, musk oxen carcasses and a reduced access to lemmings living under the snow. With the transition to summer migrating birds return, lemmings appear on terrain surface, and the ice-free shore offers washed up food items from the ocean. All together, the result is a marked change in food availability between the two seasons. Also during the short arctic summer the selection of prey species change as eggs turn to young birds that eventually fledge. Geese arrive to moult in the coastal open waters and lakes. Trout migrate up and down the river and become easy prey during passage of shallow waters. The change in accessibility and selection of prey therefore opposes some demands on the arctic fox in regard to flexibility. Natural selection must have resulted in a plastic behavioural pattern in relation to feeding strategy and searching – and hunting behaviour allowing foxes to change behaviour according to type of prey available. In this study we aimed to investigate arctic fox forage strategy during summer.

In June four adult animals were caught and radio collared with 25g Biotrack TW-3 radio transmitters (Tab. 1) . Radio tracking were performed on a daily basis followed by focal observations when possible. Tracks were followed in the snow and mapped by means of a GPS. Dens were monitored every day or every second day. Signs of activity (digging, foot prints), pup number and presence, and leftovers were registered. Three natal dens were found with 6, 6 and 5 pups respectively. Adults

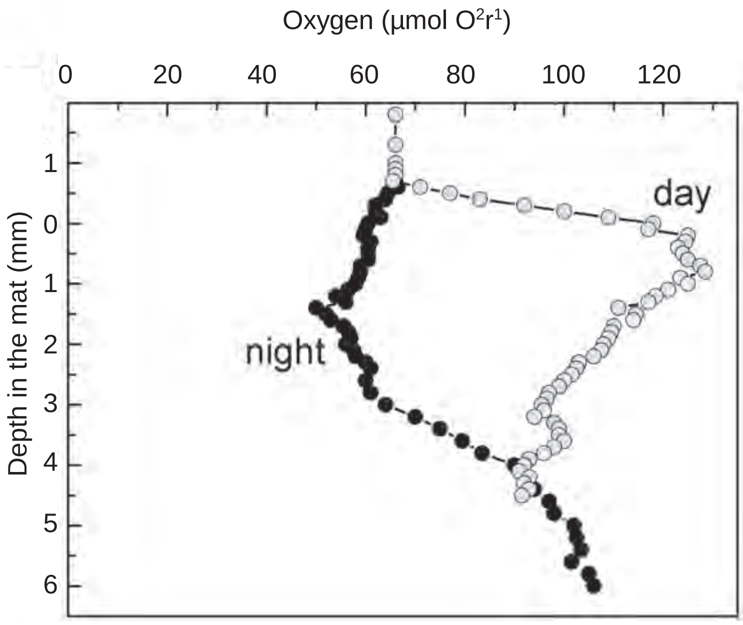


Figure 5.7. A thick microbial mat from the hottest spring on Greenland found at Kap Tobin, Scoresbysund (A). The mat was found in 50-55ºC hot water and consisted, like the Daneborg microbial mat, of a dense network of filamentous cyanobacteria imbedded in a slimy exoplymer matrix. The microbial mat soaked up oxygen produced in the light by cyanobacterial photosynthesis and excess oxygen diffused to the overlaying water (B). During nighttime where the irradiance was weakest, the microbial mat was a sink for oxygen, which diffused into the mat from the overlaying water. However, the large pool of oxygen in the mat and the apparent low oxygen consumption prevented anoxic conditions to build up in the mat. The mat thus seems to be oxic through most of the Arctic summer as long as the irradiance level can ensure a higher daily oxygen production than consumption.

from all three natal dens used the same coastal habitats for scavenging and/or fishing and hence, showed a relatively big overlap in habitat use. The female at den no. 1 foraged to a great extent on the steep mountain slopes (altitude range: 200-700 m a.s.l.) of Zackenberg, probably hunting for passerine birds, ptarmigan, and young Arctic hares and was not recorded on the east side of Zackenbergelven. Adult foxes were seen bringing gooseling, egg, arctic char and part of the content from a food depot back to the den.

Radio tracking took place from 27 June until 15 August, using 24 days for surveys. A total of 199 hours were spent in the field resulting in 9 hours and 45 minutes of direct observations. Eight of the 24 days used for surveys (33%) did not result in any observation or received signal, while 14 successful days resulted in 14 direct observations and 17 signals without observation (Tab. 1).

Even though the rate of success was low, the radio transmitters played a significant role in finding the foxes. Direct observations of foxes in the field were most often made from raised plateaux. When in motion foxes moved in straight lines with only short excursions to the side (less than 5 meters) probably when a scent or visual item was discovered. The low density of food resources may explain this behaviour. Only at one occasion an attempt of attack was observed against a wader on the tundra. Foxes were recorded visiting food depots for eating or relocating the food to nearby locations.

Fox track surveys were made on snow and along the shore in the deltas during low tide. During the period 6 – 19 June 41 fox tracks were followed in the snow. Gait, track condition, bearing, change of course, stops, markings, signs of hunting activity (*i.e.* prey remains, blood) and diggings were recorded, and position obtained by means of GPS. The tracks were followed for varying lengths depending on track condition. Generally foxes galloped in strait lines. They seldom changed direction and if changing course they often returned to the original route when continuing. They moved between snow free grounds and left these grounds in the same direction as they entered them. The attraction to snow free patches was associated with the advance of spring. The chances of finding food or prey like nesting waders were likely better on these spots in comparison with catching lemmings under the snow. Following the break-up of the fjord ice transects (3.2 km in total) were established on the shoreline and fox activity expressed as tracks was monitored at every second low tide during 30 June to 29 August. In total 42 coastal transects were walked at low tide resulting in 171 track fragments showing the same straight line pattern as the tracks recorded in the snow.

Fox ID	Sex	Weight (g)	Hours	Seen	Heard
1	female	3.370	0:26	2	5
2	male ?	3.120	4:00	3	3
3	male	3.050	0:39	2	9
4	female	2.750	3:33	5	0
X	female ?		1:06	2	0

Table 5.1. Data on the four radio tagged adult foxes and one unmarked »X«. »Hours« represent the amount of time each fox was visually observed in the field. »Seen« gives the number of sightings during surveys while »Heard« represent the number of times that only signals were received from the fox during surveys.

5.8. Physiological and genetic correlates of fitness in high arctic breeding shorebirds

Theunis Piersma and Jeroen Reneerkens

The biology of the high arctic breeding shorebirds that make up such a large proportion of the waterbirds that stage and winter in coastal wetlands in Europe and West Africa has inspired fundamental questions about the relationships between habitat selection (during the breeding season and the rest of the year) and disease resistance, the role of historical demography in these relationships, and on the roles of peculiar plumage and physiological characteristics in sexual signalling in general, and during mate choice in particular.

We have had the privilege to spend a field season at Zackenberg. We aimed to contribute to the knowledge of the breeding biology of high arctic breeding shorebirds, DNA profiles of parents and their offspring in the context of an international study on the molecular basis of immunocompetence, *i.e.* to elucidate inheritance of the Major Histocompatability Complex, the link between the production of diester preen waxes and reproductive parameters (stage of season, individual timing) and the importance of diester preen waxes in protecting feathers from wear and tear in a relevant field context. Although we successfully collected good sample sizes of blood and preen waxes of parents and offspring in several shorebird species, at this point it is too early to report on DNA profiles and the link between the production of preen waxes and reproductive parameters. Instead, we will summarize our work on population size in red knots *Calidris canutus* and sanderlings *Calidris alba*, and give the preliminary results of our work on feather wear in shorebirds during the breeding season.

An intense research effort in June-July 2003 made it possible to compare two methods to establish the breeding density of red knots: (1) the standardized mapping of displays and other activities of birds early in the season, the standard approach at Zackenberg for many years, and (2) systematic 'roping' of potential breeding areas to disturb and then find incubating birds on, or very close to, their nests. The latter method is particular to species that rely on crypsis to avoid nest detection. During 16 and 19 June Hans Meltofte mapped all visual observations of red knots over the 4.0 km^2 study area (Figure 5.8; section 3.3), which mainly consisted of low-angle mountain slopes between altitudes of 100 and 400 m, and interpreted these observations according to strict guidelines as representing 8-9 pairs. Nearby observations allow for 1-2 additional pairs. Between 17 June and 4 July the Dutch team of five observers systematically roped the same study area and found two nests (Fig. 5.8; both were lost to predators before hatch). Most of the study area remained under daily scrutiny until 19 July, and during these visits we encountered a total of two families, one with four freshly hatched chicks and one with an 11 day old chick. Even if both families originated from the roped area, the roping effort failed to confirm half the potential breeding pairs. For sanderling, a species in which incubating birds also rely on crypsis but tend to move away from nests when observers are still far away (and still escape detection), visual observations suggested 13-17 breeding attempts. The roping effort yielded 15 nests with a further seven families detected afterwards. Thus, the sanderling observations give us confidence that the discrepancy identified for red knots is not incidental and may imply that (1) visual observations overestimated the knot-population, (2) nests were depredated before roping, (3) incubating birds escaped notice during roping, and/or (4) part of the local population may not have started a breeding attempt. We find it most likely that several of these factors were involved, including the presence of non-breeding individuals. Calculations based on assumptions on brood sizes at fledging, post-fledging mortality and measured juvenile percentages on the wintering grounds are consistent with the idea that in some years part of the red knots returning to the tundra breeding grounds do not produce any juveniles – either because of failure or because they never engage in breeding. If one is interested in the population size using a certain area it is necessary to monitor numbers of pairs 'attempting' to breed, rather than those that have successfully produced offspring.

High arctic breeding shorebirds possess a small nipple-like gland that secretes mixtures of waxes that are smeared onto the

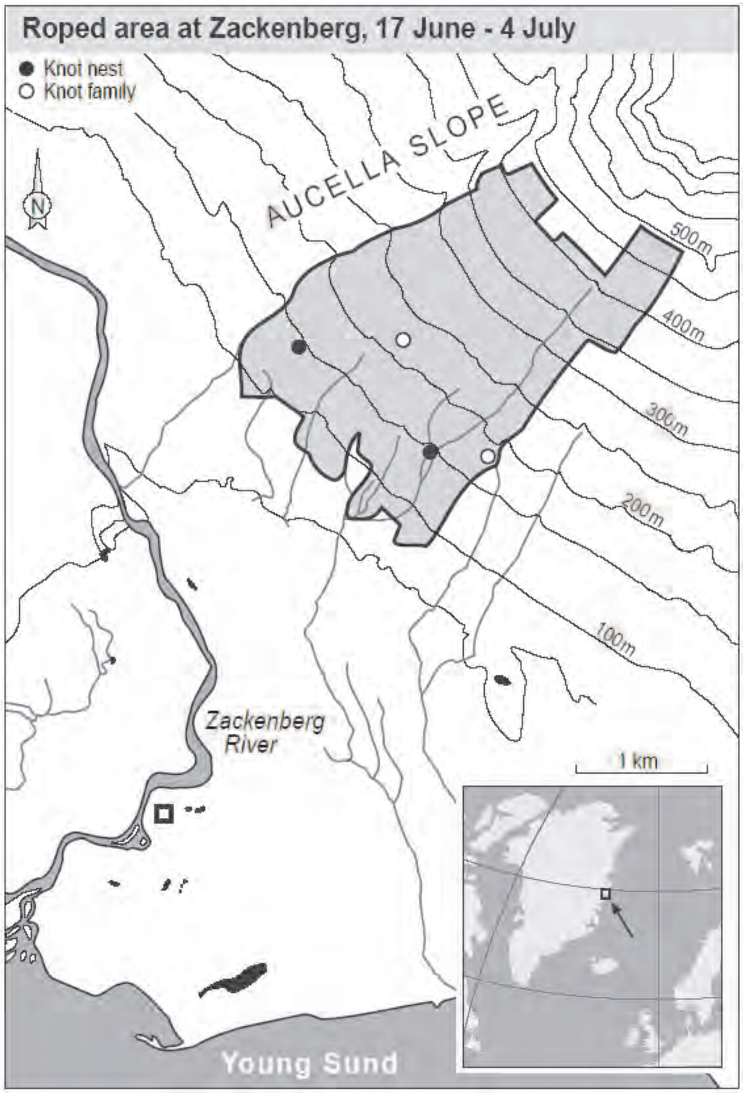


Figure 5.8. Zackenbergdalen with the study area covered by roping indicated with grey shading. The locations of the two red knot nest finds are indicated by closed dots, and the first-encounter locations of the two families are indicated with open circles.

Figure 5.9. The lack of sea ice in the last few years has changed the shape of Sandøen. When sea ice is absent during summer, large swells coming from the Greenland Sea erode the shores of Sandøen. In recent summers the exposed eastern side of the island has been washed away fast whereas sand has been deposited on the western and northern sides. The speed of erosion is illustrated by the appearance in 2003 of a ca. 2.5 m-high rock of gneiss which was buried in the cliff in 2002. In the background Wollaston Forland (Photos E.W. Born).

plumage by means of the bill. A recent discovery that the chemical composition of preen wax of high arctic shorebirds changes rapidly during the period of incubation (Reneerkens *et al*. 2002), raised questions about the function(s) of such preen waxes. One of the most heard, but to our knowledge, never tested hypothesis is that a layer of wax on the feathers protects feathers against tear and wear. During the incubation period we caught both of the incubating adults from the nest with clap-nets. After capture we measured body dimensions such as wing, bill and tarsus length and weight. A small smear from the preen gland for chemical analysis was collected and the tips of both the left and right eigth primary were collected for examination of feather wear before experimental treatment. The treatment consisted of removing preen wax from one of the wing tips by dissolving the wax into ethyl acetate, a potent solvent of hydrophobic waxes. After this treatment the birds were released. In 27 cases we caught the same individual birds again after an average of eight days (range 1- 28 days) and collected feather tips of the ninth primary feather. The null-hypothesis was that removing preen wax would not result in different abrasion of the wing feathers. The feather tips were studied with a dissection microscope to yield a 'total abrasion score'. The control feather tips (primary 8) were no different from one another, and there was also no detectable difference in abrasion scores between the ninth primaries with and without preen wax. Thus, at this point we found no support for the idea that the specific preen waxes of the breeding season give additional protection against feather wear in incubating birds. Instead, we are now investigating whether the preen waxes of the breeding season are less smelly than the preen waxes produced at other times of the year, and thereby give the birds protection against predators using olfactory cues such as arctic foxes.

5.9. Walrus studies on Sandøen

Erik W. Born, Liselotte W. Andersen, Ian Gjertz, Lars Heilmann and Lars Øivind Knutsen,

Walruses can be individually identified from their genetic profile (*e.g.* Andersen *et al*., 1998; Andersen and Born, 2000).

In 2002, the Greenland Institute of Natural Resources, Nuuk, in co-operation with the Danish National Environmental Research Institute, Department of Coastal Zone Ecology (Rønde), initiated a two-year study at the walrus haul-out on the island of Sandøen in Young Sound (Born *et al*. 2003). The main purpose of the study is (1) registration of as many individual walruses as possible by means of their genetic profile, and (2) photo-identification of individual walruses.

The overall objectives of the study are (1) to determine the number of walruses using the Sandøen haul-out and the Young

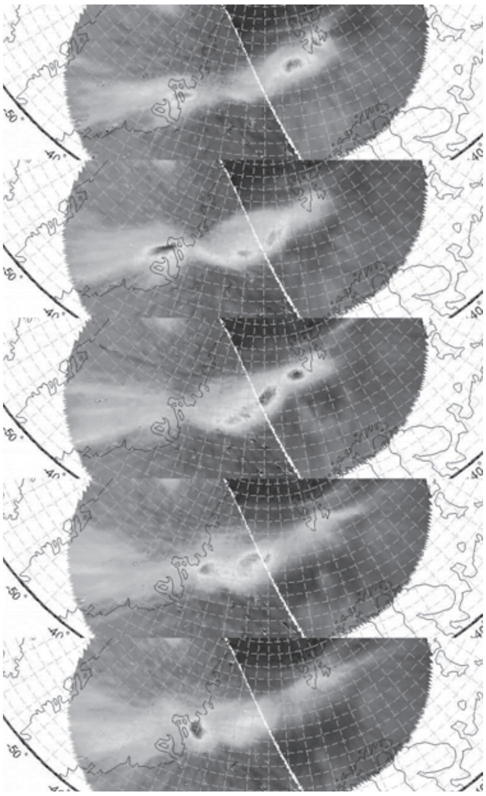


Figure 5.10. Beginning of quasi-periodic aurora events, observed by ITACA2 19 December 2002. The five images, corresponding to 09:58, 10:01, 10:03, 10:07 and 10:09 UT (from top to bottom), were obtained by combining the images recorded at Daneborg (left) and at Ny-Ålesund (right).

Sound feeding areas based on a “mark-recapture” estimate of naturally marked animals, and (2) to determine site fidelity of walruses in the area.

Similar to the situation in August 2002, ice was almost absent from the area during the field period (26 July – 23 August 2003) and swells coming from the Greenland Sea made the eastern side of Sandøen unattractive to walruses wanting to haul-out. Therefore, the walruses hauled out in several places on the southern, western and northwestern sides of the island. The maximum number of walruses recorded on a single occasions was 37 that rested on the western side of Sandøen during 1 an 2 August. During August, two female each accompanied by a calf occurred among the group consisting mainly of adult males..

Using the same methods as in 2002, a total of 214 skin biopsies were taken from walruses that rested on the island. At the same time, efforts were made to obtain ID-photos of all animals that visited Sandøen. Preliminary results of the genetic analyses involving 11 nuclear markers (*i.e.* “microsatellites”) indicate that the Sandøen haul-out was used by a total of 38 different walruses in 2002, and 81 different walruses during August 2003. Among these were 17 “recaptures” from 2002.

As described in the ZERO Annual Rapport 2001 (Caning and Rasch 2003) initiated in Daneborg to quantify the number of walruses feeding in Young Sound. The objective was to quantify the number of swimming and diving walruses at Daneborg. The same study area used in 2001 was in 2002 marked by buoys and the same type of observations took place. The weather conditions the first two weeks were very windy and misty which made the observations from Daneborg very scarce. The sea-ice was exceptional Northerly this year, which resulted in very strong waves. A big part of Sandøen was eroded by the sea, which seemed to disturb the walruses with the result that the walruses choose different haul-out places for every period spent on Sandøen.

5.10. ITACA² – Dayside aurora joint observations in the Greenland-Svalbard region

S. Massetti, M. Candidi, P. Cerulli-Irelli and M. Maggiore

In the winter season of 2002-2003 we started the first joint ground-based observations of the dayside auroral activity in the Greenland-Svalbard region. The observations were made by two automatic all-sky cameras located in Daneborg and Ny-Ålesund, Svalbard, which lie nearly along the same geomagnetic latitude of 76° N. The distance between the two sites, about 950 km, makes the field-of-view of the two instruments overlap when observing the high-altitude dayside red auroras (630.0 nm), occurring at a height of 200-500 km.

19 December 2002, ITACA² recorded a remarkable dayside event consisting of a sequence of quasi-periodic auroral forms travelling from east to west (Figure 5.10), driven by a strong positive IMF B_y component of the interplanetary magnetic field. Contemporary ground magnetic ultra-low-frequency (ULF) irregular pulsations, in the Pc5 range (*c.* 1-5 mHz), were recorded throughout the Greenland chains of magnetometers. By analysing the horizontal component of the geomagnetic pertur-

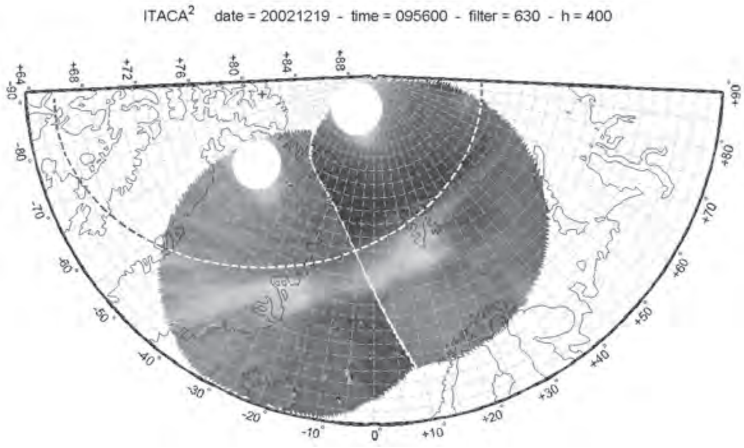


Figure 5.11. ITACA2 images at 09:56 UT projected over a map by assuming an auroral mean emission height of 400 km. The longitudinal bifurcation of the cusp red aurora is clearly visible: the aurora spot over the east coast of Greenland, is expected to be magnetically conjugated with the southern cusp, while the aurora spot over Svalbard is linked to the local northern cusp (see text for details).

bations, we identified the signatures of a series of travelling convection vortices, moving westward across Greenland. These can be seen as the footprints of field aligned currents that couple the magnetosphere to the ionosphere. We found that the red aurora intensity and magnetic perturbations observed at Daneborg are well correlated. This indicates a relationship between the observed aurora activity, which was caused by magnetic reconnection at the magnetopause at/near the cusp region, and the development of the irregular ULF Pc5 pulsations. These were reported to occur during IMF B_y dominated conditions. It was suggested that such ULF activity could be caused by *Kelvin-Helmholtz* instability, arising at the convection reversal boundary due to the high shear flows. The magnetic reconnection acting at the cusp, witnessed by the aurora activity we monitored, would be the driver of this instability. Another noticeable feature that was observed during the development of the event, was the so-called longitudinal cusp bifurcation of the aurora (Figure 5.11): a phenomenon that is expected to be the signature of high-latitude antiparallel magnetic reconnections, acting at the same time in both the northern and southern hemispheres. For a positive IMF B_y component, the aurora brightening on the west-side (that is, over the east coast of Greenland) is magnetically connected to the southern cusp, while the one on the east-side (over Svalbard) is linked to the local northern cusp. The separation between the two brightenings is estimated to be about 600 km, which is somehow wider than previously reported.

5.11. Geo-Arch 2003. Coastal landscapes, man and the environment in Northeast Greenland

Bjarne Holm Jakobsen, Claus Andreasen, Mikkel P. Sørensen and Henrik Sulsbrück Møller

An interdisciplinary expedition was carried out from the Zackenberg Research Station between 20 July and 18 August as a coordinated geographical and archaeological survey studying landscapes and settlements along a 250 km coastline in Lindeman Fjord, Wollaston Forland, Young Sund and Tyrolerfjord. The expedition was organized by The Royal Danish Geographical Society in cooperation with the national museums in Denmark and Greenland. The aim of the expedition was to collect data on Eskimo settlements (2500 B.C. – 1900 A.D.), living conditions, environment and environmental change in a well-defined coastal landscape in central East Greenland.

During more than 4000 years, Eskimo cultures have left permanent traces from several periods of settlement in the landscape. The cultural landscapes are characterized by innumerable settlement finds like tents and houses, kitchen middens, graves, cairns and tools.

The distribution of finds shows the changing environmental conditions (*e.g.* changing relative sea level, varying ice coverage in near coastal waters and varying luxuriance of landscape vegetation) during the later part of the Holocene, and gives a picture of different cultures migrating to central East Greenland from both south and north. For shorter or longer periods these cultures adapted to the natural conditions using local resources.

Studies of coastal landscape geomorphology and sedimentation in lagoons and lakes indicate a relative sea level fluctuating close to present sea level for the last 5-6000 years, probably following a rapid relative landrise of at least 60 meters immediately after deglaciation. Indications were found of settlements at relative sea levels slightly lower than at present, and with different sea ice cover than at present.

Today many beach ridges and coastal barriers indicate a rising sea level, and together with the present situation with very little sea ice along the east coast of Greenland this gives rise to high rates of coastal erosion also affecting former Eskimo cultural landscapes. The observed present coastal retreat along the exposed outer shores of NE Greenland suggest that the present conditions with very little sea ice is unique compared to the last 4000 years.

Rich settlement finds show that the cultural groups Independence I, Independence II, Dorset and Thule have all been present, and probably have been migrating in from both south and north. Additionally, weak indications of a possible presence of the Saqqaq-culture were also observed. Most Paleo- and Neo-Eskimo settlements are situated close to areas where wind conditions and sea current result in extensive open water conditions. Analyses of summer and winter dwellings show that several settlement sites have been more permanent than seasonal. Among the more spectacular finds are different types of 'toy houses' from the Thule culture, so far unknown types of flagging in settlement structures probably from the Independence II/Dorset period and a basaltic raw material site probably from the Thule period.

Observations made by the 2003 GeoArch expedition allow us to establish a rough but comprehensive model of coastal landscape conditions and resources, resource management and human strategies and survival under changing climate conditions in Central East Greenland during the last 4500 years.

5.12. Dispersal of invertebrates and plants by vertebrates in Zackenbergdalen

Kirsten Christoffersen, Marianne Philipp, Hans Henrik Bruun and Rebekka Lundgreen

The aim of the project is to study how and to what extent arctic invertebrates and plants can be dispersed through faeces of vertebrates (endozoochory), and how such dispersal routes are influencing the biodiversity of an arctic area. The study is a joint venture between a zoologist and botanists from University of Copenhagen, Denmark, and University of Lund, Sweden.

It is know from recent studies performed in Sweden, that seeds of a number of arctic plant species can pass through the digestive tract of the arctic fox and remain alive. It has also previously been shown that birds can transport eggs or resting stage of crustaceans and protozoans on their plumage over certain distances. There is, however, little known of whether other vertebrates can function as potential carriers of eggs or diasporas. Experiences from temperate regions indicate that the vertebrates found in the arctic areas may have the ability.

The present project has therefore been initiated to elucidate the role of vertebrates, *i.e.* musk ox (*Ovibos moschatus*), arctic hare (*Lepus arcticus*), arctic fox (*Alopex lagopus*) and barnacle goose (*Branta leucopsis*), in a high arctic area as vectors for dispersal of reproductive stages from aquatic invertebrate and higher plant.

A number of plots with droppings from geese (10 plots), musk ox (10 plots), arctic fox (10 plots), or arctic hare (5 plots) within a radius of 10 km from Zackenberg field station were selected and sampled during July and August. Samples were taken from the droppings directly as well as from free-live aquatic invertebrates (*Daphnia pulex* and *Lepidurus arcticus*) or from plants in a well-defined vicinity of the droppings. The entire community structures of the respective aquatic and terrestrial biotopes of each plot were intensively sampled as well. Samples were fixed with alcohol, frozen or semi-dried and kept refrigerated until morphological and genetic analyses could be made in designated labs in Denmark.

The droppings were weighed and then dissolved in water and pre-screened to enumerate seeds and other resting stages. These were placed in appropriate growth media and left to develop in climate rooms with suitable climate conditions. Only a fraction of the samples have been analysed so far. It appeared that diaspores from several plant species were found in geese and musk oxen droppings. Some of the diaspores have germinated in particular large numbers from *Polygonum viviparum* and *Ranunculus sp*.

A grant from the Carlsberg Foundation received after the field campaign will ensure that numerous genetic analyses can be made. Together with the morphological analyses as well as germination and growth experiments these will hopefully provide some new insight in the complex of interactions that determines the biodiversity of an arctic area.

6 Disturbance in the study area

Hans Meltofte

Surface activities in the study area

The number of 'person-days' (one person in the field one day) spent in the terrain in the main research zone 1 (Table 6.1) was higher than in the two previous 'low' years. The number of visits in zone 1b, the 'low impact study area', was 2-3 times higher than in previous years, while visits in zone 1c, the 'goose protection area', were as low as in previous years.
All trips with the Argo all terrain vehicle were along the 'roads' to the climate station (3) or down to the coast in the delta of Zackenbergelven (15).

Aircraft activities in the study area

The aircraft activity in 2003 (Table 6.2) was also higher than in the previous two years, while no helicopter passages took place.

Discharges

As in previous years, combustible waste (paper etc.) was burned at the station, while plastics, cans, bottles etc. were flown out of the area. On 13 June, water closets were established, so that toilet waste went directly into the river. Solid but biologically degradable kitchen waste from June was poured untreated into Zackenbergelven on 28 June, while during the rest of the season it went through a grinding mill and into the river.

During storage of the waste in June, July and August, a total amount of about 100 g 'Vera-flue-safe' was added as a killing agent against fly maggots. The active chemical is cyromazine (N-cyclopropyl-1,3,5-treazine-2,4,6-triamine) in a concentration of 2%. The total amount of untreated wastewater and solid waste let into Zackenbergelven from the toilets, kitchen, showers, sinks and laundry machines equalled *c.* 1120 'person-days'.

Research zone	May	June	July	Aug.	Sept.	Total
1	2	192	328	263	6	791
1b		12	49	31		92
1c (20.6-10.8)			6			6
2			6			6
ATV-trips						0

Table 6.1. 'Person-days' and trips in the terrain with an All Terrain Vehicle allocated to the research zones in the Zackenberg study area 27 May – 2 September 2003. Trips on roads to the climate station and the delta of Zackenbergelven are not included.

	May	June	July	Aug.	Sept.	Total
Fixed-wing aircraft	7	12	13	26	2	60
Helicopter						0

Table 6.2. Number of flights with fixed-winged aircraft and helicopters, respectively, over the study area in Zackenbergdalen 27 May – 2 September 2003. Each ground visit of an aircraft is considered two flights.

Manipulative research projects

At two sites on the slopes south of the research station (site 1: UTM-zone 27:8,264,000 mN, 512,700 mE; site 2: UTM-zone 27:8,263,800 mN, 513,000 mE) 2x12 plots measuring 0.24 m^2 each were provided with transparent filters with different UV-absorbing properties during 20 June – 16 August. Leaves of *Vaccinium* and *Salix* were sampled (100 and 5-10, respectively) during the same period and 2x16 soil samples were likewise collected.

At the slope south of and close to the station workshop (UTM zone 27:8,264,400 mN, 512,750 mE) 40 *Salix*-branches, each with 2-5 leaves, were exposed to different UV-levels by means of small frames during 20 June – 16 August with successive harvest of all the leaves (see section 5.1).

Take of organisms and other samples

In August, 200 juvenile arctic char were collected from Zackenbergelven and Store Sø (see section 5.2), and as usual a few hundreds adult arctic char were caught off the old trapping station by the Sirius Dogsledge Patrol. As part of the BioBasis programme, a total of 70,800 land arthropods were collected during the season (see section 3.2). In connection with the project on dispersal of invertebrates and plants (see section 5.12) a small number of leaves from various plants were removed in different sites. Six male and six female arctic willow stems were collected 15-20 m from the Salix 4 monitoring plot besides 74 stem samples taken from scattered locations in the valley for tree ring growth analysis (see section 5.3). Soil samples were collected near arthropod plots 3, 4 and 5 in order to quantify the soil inhabiting invertebrates and soil respiration. Nine replicates were taken in an area of 10x10 m no closer than 10 m from the arthropod plots (see section 5.6). 20 soil samples were collected scattered in Zackenbergdalen in order to determine the fungi-species present in various habitat types (see section 5.4).

7 Logistics

Henrik Philipsen

Zackenberg Research Station was open for 99 days from 27 May to 2 September. In this period, 27 scientists, 13 official guests and 6 logisticians visited and worked at the station. At Zachenberg's branch facility in Daneborg 14 scientists and two logisticians were accomodated from 29 July to 1 September. The total number of person days at both places was 1597.

Transportation

There were 58 fixed wing take off and landings with aircrafts. 20 were landings with personel to the station, one carried guests, and nine landings were with cargo. Local transportation was done by an All Terrain Vehicle on marked roads and included three trips to the climate station and 15 trips to the beach with supplies to the faciliites in Daneborg. The All Terrain Vehicle broke one of its eight axles but was repaired immediately.

Zackenberg has now three rubber boats. A new Maru RIB 5.4 m rubber boat with a 50 HP four stroke engine was brought to Zackenberg. Our old Zodiac rubber boat has been in Denmark for repair and is working fine again.

Housing

Guests were accommodated in Wheatherheaven shelters, while the staff lived in five single rooms in wooden houses. All houses and shelters are in good condition.

Water and power supply

Two 14.8 kW generators supplied the station with electricity, and five smaller generators were used for field work.
The Zackenberg water plant worked successfully. Two new toilets with electric shredders were installed.

Telecommunication

Communication outside Northeast Greenland is done by satellite telephone. An iridium satellite telephone was purchased to supplement the existing Inmarsat satellite telephone. Telephone communication totaled 1295 minutes. 1008 e-mails were send and received through the server at the Institute of Geography, University of Copenhagen.

Medical services

Minor damages such as blisters, a sprain thumb and a bad stomach were treated.

Daneborg

The branch facility in Daneborg was supplied with a generator, water pipes, fuel, technical equipment and food.

Expeditions

A geological-arhcaeological expedition was supplied with tents, sleeping bags, food, stoves, a 300 W generator, fuel, HF radio, rifles and a Zodiac.

8 Personnel and visitors

Compiled by Morten Rasch

Research

Zackenberg

Claus Andreassen, Greenland National Museum and Archives (Geo-archaeology, 22 July – 19 August)
Thomas Bjørneboe Gomes Berg, National Environmental Research Institute (BioBasis, 26 June – 2 September)
Hans Henrik Bruun, Lund University (biodiversity, 12 – 19 August)
Kirsten Christoffersen, Institute of Zoology, University of Copenhagen (biodiversity, 29 July – 12 August)
Henning Damgård, ASIAQ, Greenland Survey (ClimateBasis, 5-19 August)
Welmoed Ekster, Royal Netherlands Institute for Sea Research, the Netherlands (Ornithology, 16 June – 22 July)
Zdenik Gavor, National Environmental Research Institute (Soil fauna, 29 July – 5 August)
Petra de Goelj, Royal Netherlands Institute for Sea Research, the Netherlands (Ornithology, 16 June – 22 July)
Odd A. Gulseth, Brattøra Research Centre, Trondheim, Norway (Arctic char, 5-19 August)
Birger Ulf Hansen, Institute of Geography, University of Copenhagen (GeoBasis, 22 July – 5 August)
Jørgen Hinkler, Institute of Geography, University of Copenhagen (Snow cover and GeoBasis, 3–16 June)
Kirsten Håkanson, Botanical Institute, University of Copenhagen (UV-B radiation, 16 June – 19 August)
Bjarne Holm Jakobsen, Institute of Geography, University of Copenhagen (Geo-archaeology, 22 July – 12 August)
Joop Jukema, Royal Netherlands Institute for Sea Research, the Netherlands (Ornithology, 16 June – 22 July)
Line Anker Kyhn, National Environmental Research Institute (BioBasis and fox ecology, 3 June – 2 September)
Rebekka Lundgren, Institute of Botany, University of Copenhagen (biodiversity, 12 – 19 August)
Hans Meltofte, National Environmental Research Institute (BioBasis, 3 June – 5 August)
Teis N. Mikkelsen, Research Center Risø (UV-B radiation, 16-26 June)
Henrik Sulsbrück Møller, Institute of Geography, University of Copenhagen (Geo-archaeology, 22 July – 19 August)
Riika Niemi, Botanical Institute, University of Copenhagen (UV-B radiation, 12-19 August)
Kjell J. Nilssen, Norwegian University of Science and Technology, Tromsø, Norway (Arctic char, 5-19 August)
Jonathan N. K. Petersen, ASIAQ, Greenland Survey (ClimateBasis, 5-19 August)
Marianne Philipp, Institute of Botany, University of Copenhagen (biodiversity, 5 – 19 August)
Theunis Piersma, Royal Netherlands Institute for Sea Research, the Netherlands (Ornithology, 16 June – 22 July)
Helge Ro-Poulsen, Botanical Institute, University of Copenhagen (UV-B radiation, 12-19 August)
Niels Martin Schmidt, The Royal Veterinary and Agricultural University (Botany and insect pathogens, 3-29 July)
Jeroen Reneerkens, Royal Netherlands Institute for Sea Research, the Netherlands (Ornithology, 16 June – 22 July)
Charlotte Sigsgaard, Institute of Geography, University of Copenhagen (GeoBasis, 3 June – 3 September)
Mikkel Sørensen, The National Museum of Denmark (Geo-archaeology, 22 July – 19 August)
Louise Illum Sørensen, National Environmental Research Institute (Soil fauna, 29 July – 5 August)
Mikkel P. Tamstorf, National Environmental Research Institute (GeoBasis, 3-16 June)

Daneborg

Liselotte Andersen, National Environmental Research Institute (Walruses, 29 July – 19 August)
Erik W. Born, Greenland Institute of Natural Resources (Walruses, 29 July – 19 August)
Pasquale Cerulli-Irelli, IFSI/CNR, Italy (Aurora, 22-29 July)
Peter Bondo Christensen, National Envi-

ronmental Research Institute (MarineBasis, 5-26 August)
Egon R. Frandsen, National Environmental Research Institute (MarineBasis, 5-26 August)
Ian Gertz, The Research Council of Norway, Norway (Walruses, 12 August – 3 September)
Lars Heilmann, Greenland Institute of Natural Resources (Walruses, 12 August – 3 September)
Lars Øyvind Knutsen, Cinenature, Sweden (Walruses, 29 July – 12 August)
Marco Maggiore, CNR Network Support, Italy (Aurora, 22-29 July)
Stefano Massetti, IFSI/CNR, Italy (Aurora, 22-29 July)
Søren Rysgaard, National Environmental Research Institute (MarineBasis, 5-26 August)
Mikael Sejr, University of Aarhus (MarineBasis, 5-26 August)

Logistics

Zackenberg

Laust Pedersen, Danish Polar Center (15 July – 5 August)
Stig Pettersson, Danish Polar Center (22 July – 5 August and 19-26 August)
Henrik Philipsen, Danish Polar Center (26 May – 2 September)
Morten Rasch, Danish Polar Center (30 May – 16 June and 12-26 August)
Bjarne Schmidt, Danish Polar Center (26 May – 22 July, 3–19 August and 26 August – 2 September)
Anna-Isabella Petersen (30 May – 2 September)

Daneborg

Laust Pedersen, Danish Polar Center (5 August – 2 September)
Stig Pettersson, Danish Polar Center (5–19 August)
Henrik Philipsen, Danish Polar Center (26 May – 2 September)
Bjarne Schmidt, Danish Polar Center (22 July – 3 August and 19-26 August)

Others

Zackenberg

Thomas Adelskov, Danish Parliament's Committee for Science and Technology (19-21 August)
Leo Bjørnskov, Ministry of Science, Technology and Innovation (19-21 August)
Flemming Damsgaard Larsen, Danish Parliament's Committee for Science and Technology (19-21 August)
Jørn Dohrmann, Danish Parliament's Committee for Science and Technology (19-21 August)
Magnus Elander, Sweden (22-23 August)
Daniel Grossman, WBUR, Boston, USA (24-29 July)
Anne Grete Holmsgaard, Danish Parliament's Committee for Science and Technology (19-21 August)
Lene Jensen, Danish Parliament's Committee for Science and Technology (19-21 August)
Bodil Kornbek, Danish Parliament's Committee for Science and Technology (19-21 August)
Thorkild Meedom, Ministry of Science, Technology and Innovation (19-21 August)
Hanne Petersen, Danish Polar Center (19-21 August)
Jesper Schaumburg-Møller, Danish Parliament's Committee for Science and Technology (19-21 August)
Hanne Severinsen, Danish Parliament's Committee for Science and Technology (19-21 August)

Daneborg

Magnus Elander, Sweden (19-22 August and 23-26 August)
Göran Ehlme, Water Proof Diving International AB (filming walruses, 5-26 August)

Further contributors to the annual report

Kristian Albert, Botanical Institute, University of Copenhagen
Jørgen Eilenberg, Royal Veterinary and Agricultural University
Mads C. Forchhammer, Zoological Institute, University of Copenhagen
Thomas Friborg, Institute of Geography, University of Copenhagen
Ronnie Glud, Marin Biological Laboratory, University of Copenhagen
Louise Grøndahl, National Environmental Research Institute
Martin Holmstrup, National Environmental Research Institute
Erik Jeppesen, National Environmental Research Institute
Mogens Lind Jørgensen, National Environmental Research Institute.

Michael Kühl, Marine Biological Laboratory, University of Copenhagen
Hans Pedersen, Marine Biological Laboratory, University of Copenhagen
Dorthe Petersen, Asiaq, Greenland Survey
Christian Wolsted, Royal Veterinary and Agricultural University

9 Publications

Compiled by Vibeke Sloth Jakobsen

Scientific papers

Berg, P., Rysgaard, S. & Thamdrup, B. 2003: Dynamic modeling of early diagenesis and nutrient cycling : a case study in an Arctic marine sediment. – American journal of science 303 : 905-955

Berg, T.B. 2003: Catechin content and consumption ratio of the collared lemming. – Oecologia 135 : 242-249

Born, E.W., Rysgaard, S., Ehlmé, G., Sejr, M., Acquarone, M. & Levermann, N. 2003: Underwater observations of foraging free-living walruses (*Odobenus rosmarus*) including estimates of their food consumption. – Polar biology 26(5) : 348-357

Christensen, T.R., Joabsson, A., Strom, L., Panikov, N., Mastepanov, M., Oquist, M., Svensson, B.H., Nykanen, H., Martikainen, P. & Oskarsson, H. 2003: Factors controlling large scale variations in methane emissions from wetlands. – Geophysical research letters 30 : 1414

Hansen, A.S., Nielsen, T.G., Levinsen, H., Madsen, S.D., Thingstad, F. & Hansen, B.W. 2003: Impact of changing ice cover on pelagic productivity and food web structure in Disko Bay, west Greenland : a dynamic model approach. – Deep sea research 50 : 171-187

Illeris, L., Michelsen, A. & Jonasson, S. 2003: Soil plus root respiration and microbial biomass following water, nitrogen, and phosphorus application at a high arctic semi desert. – Biogeochemistry 65 : 15-29

Levermann, N., Galatius, A., Ehlmé, G., Rysgaard, S. & Born, E.W. 2003: Feeding behaviour of free-ranging walruses with notes on apparent dextrality on flipper use. – BMC ecology 3 : 9

Petersen, J.K., Sejr, M.K. & Larsen, J.E.N. 2003: Clearance rates in the arctic bivalves Hiatella arctica and Mya truncata. – Polar biology 26(5) : 334-341

Risgaard-Petersen, N., Nielsen, L.P., Rysgaard, S., Dalsgaard, T. & Meyer, R.L. 2003: Application of the isotope pairing technique in sediments where anammox and denitrification co-exist. – Limnology and oceanography, methods 1 : 63-73

Rysgaard, S., Vang, T., Stjernholm, M., Rasmussen, B., Windelin, A., Kiilsholm, S. 2003: Physical conditions, carbon transport, and climate change impacts in a Northeast Greenland fjord. – Arctic, Antarctic, and Alpine research 35(3) : 301-312

Strom, L., Ekberg, A. & Christensen, T.R. 2003: Species-specific effects of vascular plants on carbon turnover and methane emissions from a tundra wetland. – Global change biology 9 : 1185-1192

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